NBS WAR RESEARCH

The National Bureau of Standards in
World War II

by Lyman J. Briggs

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Foreword

The preparation of this account of the work of the National Bureau of Standards was undertaken in accordance with the request of the Secretary of Commerce, who wrote, on October 11, 1945, "... I very much wish that you would prepare at your leisure, but complete in the not too distant future, an account of the part played by the Bureau of Standards in winning the war. You owe it to yourself, to the Bureau, to the Department, and to the country to shake off some of your customary modesty and let the world know something of what was done."

In this undertaking, I have had the cordial support of our Director, Dr. E. U. Condon, and the hearty cooperation of the members of the staff. The report has been written for the most part, as it should be, by those who carried out the investigations. Unfortunately, it has not been found practicable to give specific credit to all the men and women who worked so conscientiously and faithfully under great stress; nor to include the scores of commendatory letters received from various branches of the Army and Navy expressing appreciation of the Bureau's assistance on specific war projects.

I wish to record my deep obligation to the assistant directors and division chiefs who helped to carry the administrative load during the war. To the members of the entire staff I wish to express my pride in their ability, their loyalty, their unity and their determination to get the work done. To them belongs the credit for the Bureau's accomplishments. I extend to them my heartfelt appreciation and affection.

LYMAN J. BRIGGS, Director Emeritus

August 15, 1946.
1. The Over-all Program

The war work of the National Bureau of Standards began with the initiation of the defense program. Yet before that time the Bureau had been working with other Government agencies in investigations that proved applicable and important in the war, and the Bureau's fundamental investigations in physics, applied mathematics, chemistry, and engineering, carried on since 1901, provided a vital and timesaving background for special projects.

Typical of the prewar research done under the sponsorship of other Government agencies were the projects for the National Advisory Committee for Aeronautics and the Bureau of Aeronautics of the Navy, such as the corrosion and fatigue of light alloys, the structural strength of fabricated metals, and the wind tunnel investigations of the boundary layer of an airfoil. These investigations were significant in both the national aircraft program and in the guided missile projects: in these fields the Bureau undertook an expanded program during the war.

Perhaps the four most significant as well as striking projects in which the Bureau was engaged during the war were the atomic bomb project, the proximity fuze, guided missiles and "radio weather." Each represented a major scientific effort, and in each the Bureau took an active part in collaboration with other agencies.

The Atomic Bomb

The atomic bomb project had its genesis in the Bureau when President Roosevelt turned, in October of 1939, to the Director of the Bureau, Dr. Lyman J. Briggs, for the initiation of the program. The immediate and particular question at this time was the possibility of utilizing the nuclear fission of uranium in warfare. It was not then known which of the isotopes of uranium was subject to fission when bombarded with neutrons, nor was the number of neutrons emitted in the fission process known. The possibility of chain reactions remained to be demonstrated.

Little was known about the chemistry and metallurgy of uranium. Physical methods for separating the isotopes of uranium had yet to be developed.

The contributions of the National Bureau of Standards to this undertaking are given in the next chapter of this report.

The Proximity Fuze

The proximity fuze, considered by some as next to the atomic bomb in military importance, was another major development in which the National Bureau of Standards played a key role. This undertaking was divided into two independent parts. The development of proximity fuzes for rotating projectiles was carried out by the Navy Department under the leadership of Dr. H. A. Tuve. The corresponding development of proximity-fuzes for nonrotating projectiles such as bombs and rockets was carried out by the Bureau for the N.D.R.C. under the leadership of Dr. A. Ellett and Harry Diamond.

The radio proximity fuze is a fuze which will automatically explode a projectile if it comes anywhere within say 60 feet of the target. The advantages of such a fuze are obvious. In the case of aircraft targets, for example, the effective size of the target is greatly increased and fewer shots are wasted. Many projectiles which would otherwise miss the aircraft can be made to explode by the fuze so as to destroy the target. Its advantages against ground targets are equally significant, because the proximity fuze explodes the projectile 30 to 50 feet above the ground. Projectile effectiveness is increased from five to twenty times over that of the same projectile fitted with a contact fuze. This increased effectiveness has two major implications: first, the advantages gained in terms of attack and, second, the significance in terms of military logistics—i.e., the men and material needed for a particular operation.

The radio proximity fuze contains a small radio transmitter and receiver. It functions
by transmitting radio waves, continuously. When these waves are reflected back to the traveling projectile by an object in their path, they are picked up by the fuze receiver. At a predetermined intensity of the reflected radio waves, the reflected energy operates an electronic switch which detonates the fuze and the projectile.

The proximity fuze program was begun in 1940, and by 1941 considerable effort was devoted to it by the Bureau. During one period about 400 scientists, engineers, and technicians were assigned to this project. Work in this field was continued after the war, the Bureau serving as a research and development agency for proximity fuses for the Army Ordnance Department.

**Guided Missiles**

The third of the special military programs undertaken by the Bureau was the guided missile program. Members of the Bureau staff worked closely with the NDRC and the Navy in the development of radar homing missiles—missiles which automatically seek out their target and guide themselves to hit the target. This was one of the largest of the Bureau’s war projects, and the Bureau's great hydraulic laboratory building was given over entirely to this undertaking. In one form of this weapon, a bomb is housed in a glider which carries in its nose the necessary radar and control mechanism. The glider "illuminates" the target ship with short bursts of radio waves and directs itself toward the waves that are reflected back from the target. In making an attack the glider is carried underneath a mother airplane to a point just short of the range of gunfire and launched after being "told" what target it is to attack.

According to the official Navy release, this guided missile destroyed many tons of Japanese combatant and merchant shipping during the last year of the war. This was the famous missile BAT, developed by the Bureau. Work in this field was continued after the war for the Navy Bureau of Ordnance.

"Radio Weather"

Large military operations involving the participation of ground, sea, and air forces must be definitely scheduled well in advance of the day of attack. Failure of the all-important radio communication system on the day selected, owing to magnetic storms or similar disturbances, would jeopardize the success of the whole undertaking. Accordingly, the Joint Chiefs of Staff of our forces and the British Admiralty asked the Bureau's Radio section to undertake the forecasting of conditions which might interfere with radio communication.

Long-range radio communication depends on the reflection of radio waves from the ionospheric layers. There are ionized zones of the upper atmosphere which vary in height and in ionization with the time of the day and disturbances in the sun. To facilitate communication between any two points on the surface of the earth, extensive ionospheric data must be compiled, correlated, and analyzed. Predictions of the best frequencies to be used are then made. This phase is concerned with rather long-range forecasting. At present, for example, monthly predictions are issued three months in advance of the month covered. At the same time, short-range predictions are necessary.

Long before the war, research at the Bureau under the direction of J. H. Dellinger had shown that the appearance of sunspots is often accompanied by marked disturbances in radio communication; frequently there is a total black-out of radio waves. Accordingly, a forecasting program involving daily analysis was also developed.

So successful was the undertaking that at the end of the war the military sponsors strongly urged that a direct appropriation be made to the Bureau to continue and expand the service as a peacetime aid to air and sea navigation. This recommendation was approved by Congress, and a war-time development, born of necessity, now finds a peacetime application in safeguarding lives and shipping and in aiding transportation by air and sea.
In 1941, the new Bureau radio station (WW) for broadcasting standard radio frequencies, costing $250,000 was authorized for construction at Beltsville, Md. A limited service of this kind had been provided by the Bureau for some years, but the new transmitters were sufficiently powerful to cover not only the United States and the north Atlantic, but a part of the Pacific as well, the signals being received with ease in New Zealand. This service was utilized extensively by the Navy and Army throughout the war in maintaining the correct frequency of their countless transmitters and was widely used also by firms making radio equipment, by the Federal Communications Commission and by the broadcasting stations generally.

The standard frequencies are generated by means of a group of quartz crystal oscillators, working under rigidly controlled temperature and pressure conditions. The outgoing signals (2.5, 5, 10, 15, 20, 25, 30 and 35 mc/s) do not vary as much as one part in 60 million from the announced standard frequency. Standard audio frequencies, time signals, and ionospheric disturbances are also broadcast.

The Scope of the Program

Each of the four projects mentioned above—the atomic bomb, the proximity fuse, guided missiles, and "radio weather"—represented a major program. These programs, however, were only part of the work of the Bureau. In many ways the Bureau's work during the war reflected the elaborate and complex scope of activities which the nation had to undertake, and physics, chemistry, engineering and mathematics, were mirrored in the hundreds of projects carried on by the Bureau.

One of the important factors in this situation was the existing organization and structure of the Bureau. From 1901 the Bureau had engaged in basic research and development in the physical sciences; it had the custody of the national standards of measurement and had developed standards, methods of measurement, and instruments for measurement; it had long acted as a central physical laboratory for all other Federal agencies. The organization of the Bureau was such that specialists in many fields of the physical sciences were at work in its many laboratories, and a procedure of research had been developed which favored maximum efficiency. The complexity of modern scientific problems is such that a specialist in a particular field is often confronted with related problems in other fields. At the Bureau, these "other" specialists could usually be found. Thus problems involving many fields could be handled within the Bureau itself.

Another factor of vital importance was that the past research of the Bureau represented time and again the basis for new developments. This was true in the case of the atomic bomb, where the experience and skill of our physicists, chemists and metallurgists were drawn upon heavily in attacking this new problem. It was true in the fields of proximity fuzes, "radio weather" and guided missiles, where the years of work in electricity, electronics, and radio made rapid progress feasible.

These same factors operated advantageously in other fields. Thus, the vast synthetic rubber program of the nation required prompt and expert development, for we were cut off from the Pacific supplies of natural rubber. For years the Bureau had been investigating both natural and synthetic rubbers, and its experts contributed to the 800 million dollar program in many ways. For example, the styrene content of the GR-S copolymer is critical, and some method of conveniently and accurately determining this content was necessary; a refractive index method, studied and developed many years before, was adapted by the Bureau and solved the problem. Problems in the measurement of the purity of styrene, butadiene and other monomers were investigated as well as the densities of commercial varieties of synthetic rubber and the specific heats and thermodynamic measurements of GR-2. The development and adaptation of instruments and the development of methods of measurement were important contributions.

Aluminum presented a problem similar to that of natural rubber. The United States
is largely dependent upon foreign bauxite ore for manufacturing this critical metal. When it appeared that ore supplies might be cut off by German U-boats the Bureau successfully explored two methods of utilizing domestic clays for the production of alumina, an alkaline and an acid process. A pilot plant was built for the acid method, which was operated almost continuously for two years. It was demonstrated that high-grade alumina could be prepared from domestic clays if necessary. At present (1946) costs, imported bauxite is less expensive.

Optical glass was another field where the combination of specialists in several fields and years of work proved invaluable. The Bureau is unique in being the only Government laboratory in which work in optics includes the manufacture of glass. The broad program includes investigations of the raw materials, production of experimental as well as established types of glass, the design of instruments, the development and construction of instruments, the testing and calibration of instruments, and basic studies in optics.

Prior to the first World War, the United States was entirely dependent on European sources for optical glass. World War I cut off this supply and domestic sources were vital to the armed services. Under the sponsorship of the Navy, the Bureau undertook the production of special optical glasses. The work of the Geophysical Laboratory of the Carnegie Institution in meeting this emergency during World War I deserves special commendation.

After World War I, the Navy realized the need for maintaining such production on an experimental basis at the Bureau, and between the wars supported the Bureau in a program of research and production in this field, which in peace-time had limited commercial application. With our entry in the recent war, the Bureau's facilities were expanded, and an annual production rate of over 200,000 pounds of first-quality optical glass in the form of molded lenses and prisms was achieved during two of the war years. Aside from the production of glass, the Bureau was active in the field of optical measurements and instrumentation.

In the aircraft field the Bureau engaged in a diversified program for the Army, Navy, and the National Advisory Committee for Aeronautics. Typical of the projects undertaken by the Bureau are the following: basic research in aerodynamics, investigations of fuels and lubricants, spark plug studies, ceramic coatings for exhaust stacks, oxygen boost for engines, de-icing investigations, studies of lightning and electrostatic hazards, various problems concerned with oxygen equipment for high altitude flying, the development of scores of instruments, studies of metals and alloys, electrical problems and jet engine studies.

These illustrations suggest not only the wide scope of the Bureau's work in this single field, but emphasize the complexity of modern technology which necessitates work in many fields for the solution of the problems of a single major project. Thus, the aircraft problems mentioned above demanded attention from physicists, chemists, mathematicians, and engineers; and the staff and facilities of the Bureau, covering these fields, provided economic, consolidated means for their solution.

One of the fields apt to be overlooked, partly because it is highly specialized in nature and partly because its impact has barely begun to be felt, is that of applied mathematics. For ten years, the Bureau has sponsored a program in mathematical tables. This program, in addition to computing basic mathematical tables, contributed substantially to the national defense. Representative projects included a number of tables of grid coordinates and related tables for military maps, hydraulic tables for the U. S. Corps of Engineers, extensive anti-aircraft tables, a table of functions related to underwater bomb trajectories, tables of intensity functions for real indices of reflection, extensive tables for Loran (long range navigation), and special tables needed in nuclear physics. This work was directed by A. N. Lowan. A detailed account will be found in Scripta Mathematica, 15, p. 33-83, 1949.

Work in this field has been continued and now embraces a well-rounded program, sponsored by the Navy, Army, and the Atomic
Energy Commission. An integral part of it embraces mathematical studies, electronic and mechanical design, and the construction of automatic electronic computing machines which promise to solve problems now amendable only to costly, approximate solutions involving many manhours of time and elaborate experimental equipment and to solve problems hitherto without adequate solution. Their development and application promise to revolutionize many fields of scientific activity, ranging from basic aerodynamics to weather prediction.

Similar procedures characterized the work of the Bureau in other fields: in color and light, fuels and lubricants, electricity, mechanics and structural materials, high polymers, ceramics, metals and alloys and standards. In addition, new tools and instruments were developed; innumerable services of a testing and calibrating nature were performed for practically every agency of the Government; and advice and cooperation in the physical sciences was extended to industry and other laboratories as well as the Federal Government.

Staff and Facilities

The ability of the Bureau to undertake the almost unbelievably diversified program of work during the war stemmed from the existence of the basic staff and facilities. During the war years, an average of some 2,500 individuals comprised the staff, which worked largely in the hundreds of laboratories housed in some 20 major and 60 minor buildings on the Bureau's 68 acres of grounds in northwestern Washington. A number of field stations and proving grounds were also utilized.

However, during the seven years preceding the war, there had been almost no increase in laboratory facilities and equipment. In 1939, $500,000 dollars was appropriated for the construction and equipment of a high voltage laboratory. These facilities enabled the Bureau for the first time to carry out standardization measurements at high voltages, thus supplementing the work which it had been doing in the low voltage field since its establishment in 1901. Likewise, the installation in the new laboratory of standardizing equipment for X-rays, capable of operating up to 1,400,000 volts, made it possible for the Bureau to keep pace with the rapidly growing requirements in this field. The facilities of the high voltage laboratory were extensively used during the war in connection with the development of means for protecting wooden planes and gliders from lightning, in the standardization and testing of X-ray equipment for the Army Medical Corps and in investigations concerned with proximity fuses.

In 1940, the Bureau was authorized to purchase a tract of land comprising 12.5 acres immediately adjoining the Bureau grounds. Its acquisition was most timely, as four permanent laboratories (three of which were constructed by the War Department) were built on the property during the war, along with several minor structures. In the same year Congress appropriated $100,000 for the enlargement of the Bureau's optical glass plant. Foresight in this connection not only made it possible for the Bureau to supply a substantial part of the optical glass critically needed in the early days of the war, but also to utilize the plant as a practical training ground for the personnel of four American firms who were to undertake the manufacture of optical glass for the first time, as well as our Canadian and Australian Allies.

The present organization of the Bureau is presented in the appendix.

* * *

The story of the war years, as has been indicated, as a complex, detailed, and lengthy one. Much of it cannot be told simply because there is too much to tell. Much cannot be told because many projects were vital to the national security. Of what can be told, some typical projects have been chosen because they provide a suggestive picture of what the full program was. This history is, then, a summary which gives the scope of the problems and cites some of them as examples.
2. The Atomic Bomb

Undoubtedly the most spectacular of the projects undertaken by the National Bureau of Standards was the atomic bomb project. The large scope of the project in the period of its development and engineering phases, as well as the necessary secrecy associated with the program, tends to obscure the initial and critical two years during which much basic research was performed and the major weapon program formulated. It was in this period that the National Bureau of Standards played a key role in the project. Shortly after the initial phase was completed, the Manhattan District was established and the gigantic development and engineering of the weapon began.

Initiation of the Project

The National Bureau of Standards began its work on the atomic bomb project in October 1939 when President Roosevelt appointed its Director, Lyman J. Briggs, as chairman of a committee to investigate the possibility of utilizing the atomic fission of uranium in warfare. At this time it was not known which of the isotopes of uranium was subject to fission when bombarded with slow neutrons, or how many neutrons were emitted in the fission process. The possibility of establishing a chain reaction remained to be demonstrated. Little was known about the chemistry and metallurgy of uranium. Physical methods for separating the isotopes of uranium had yet to be developed.

The solution of such problems was undertaken by the committee with the enthusiastic cooperation of leading scientists in this field. The uranium committee recognized the future possibilities of uranium fission as a source of power but early decided to concentrate its activities on the development of an atomic bomb. The basic information gained in this study could later be applied in the development of atomic power.

Owing to the secrecy imposed on the project, the acquisition of necessary funds became a problem in itself. The initial experiments began in 1939 were financed by a transfer of $6,000 from the Ordnance Department of the Army and the Bureau of Ordnance of the Navy. This money was used to purchase materials for experiments by Dr. E. Fermi at Columbia University, to determine the suitability of graphite as a moderator to slow down fast neutrons. In 1940, through the cooperation and enthusiastic support of Rear Adm. H. G. Bowen, Director of the Naval Research Laboratory, funds to the extent of $100,000 were made available to the project at a time when they were most urgently needed.

These funds were used mainly for the study of different methods of separating the isotopes. Among them was the method of thermal diffusion proposed by P. H. Abelson, of the Carnegie Institution, who demonstrated its possibilities in his laboratory at the National Bureau of Standards, carried it successfully through the pilot plant stage at the Naval Research Laboratory, and finally saw it culminate in a great operating installation at the Clinton plant in Tennessee. Work was also started at Columbia University by J. R. Dunning on the separation of the uranium isotopes by gaseous diffusion through a porous membrane, which likewise eventually led to the construction and operation of an enormous diffusion plant at Clinton. The development of a centrifugal method for separating the isotopes was also undertaken by J. W. Beams at the University of Virginia, which was carried through the pilot plant stage with highly satisfactory yields but was held in reserve as a production method.

In June 1940 President Roosevelt established the National Defense Research Committee under the direction of Dr. Vannevar Bush and made the uranium committee a section of NDRC. This was a happy solution to the problem of securing the necessary funds for a secret project, for it was recognized at the outset that NDRC would be engaged in highly confidential work. At that time the Uranium (S-1) section was reorganized as follows: L. J. Briggs (chairman), G. B. Pegram (vice-chairman), H. C. Urey, J. W. Beams, H. A. Tuve, R. Gunn, and G. Breit. Additional
support was given by NDRC to the investigations already under way, and new work was undertaken. The possibility of establishing a chain reaction was still a matter of great uncertainty, yet upon this the success of the whole project rested. Forty tons of graphite and seven tons of uranium oxide were supplied to Fermi at Columbia for use in a further attack on this problem. New projects dealing with the chain reaction were supported at the Universities of Chicago, California and Princeton. E. O. Lawrence reported in May 1941 on experiments at Berkeley which indicated that plutonium (element 94) is formed from uranium 238 (element 92) by neutron capture followed by two beta-transmutations and that plutonium like uranium 238 undergoes fission when it captures a slow neutron. This significant discovery held great possibilities because (1) the abundant isotope 238 could be utilized, (2) separation of the uranium isotopes by physical methods was unnecessary, and (3) plutonium could be separated from the parent mass by chemical methods.

In July 1941, the membership of the S-1 section of NDRC was changed somewhat to provide representation for new activities. The meetings, as before, were held at the National Bureau of Standards and were attended by Dr. J. B. Conant as Dr. Bush's representative.

Up to this time, the expenditures for the atomic bomb project had certainly been moderate. At a meeting of NDRC on July 19, 1941, Dr. Briggs as chairman of the S-1 section reviewed the progress that had been made and presented the request of his section for an allotment of $207,000 with the statement that much larger expenditures would soon be required. This allotment was approved by NDRC and the theoretical and experimental work went forward at an increased tempo. Dr. Briggs also asked Dr. Bush in the spring of 1941 to appoint an independent committee to make an impartial review of the project and Dr. Bush requested the National Academy of Sciences to undertake this study and to recommend the level of expenditure at which the investigation should be continued.

In November 1941 Dr. Bush, after reviewing the further advances that had been made by the S-1 section and the recommendations of the Academy committee and after consultation with the President and his advisors, decided that the time had now come for the "all-out" effort. The project was transferred to OSRD as the S-1 section, which was organized as follows: L. J. Briggs (chairman), G. B. Pegram (vice-chairman), and J. B. Conant; A. H. Compton, E. O. Lawrence, and H. C. Urey, program chiefs; E. V. Murphree, chairman of the planning board; S. K. Allison, J. W. Beams, G. Breit, E. U. Condon, and H. D. Smyth. H. T. Wenzel served as technical aide to the committee.

Funds available for the work were greatly expanded. Under Lawrence the investigation of the large-scale separation of the uranium isotopes by electromagnetic processes was accelerated at the University of California. Research on the gaseous diffusion process of separating the isotopes and on the all important problem of developing suitable porous membranes that would not corrode and become clogged through the action of uranium hexafluoride was continued at Columbia University under Dunning and Pegram. H. C. Urey had supervision of methods for producing heavy water for use as a moderator and other important special assignments. Basic work relating to the chain reaction and its utilization in the production of plutonium at Columbia under E. Fermi and at Chicago under S. K. Allison was continued under A. H. Compton's direction at the University of Chicago. It was here that the chain-reaction was first demonstrated by Fermi in a graphite-uranium pile in December 1942.

By July 1942, it appeared that the final intensive work on the research and development program could be directed more effectively by a smaller group and the S-1 section was succeeded by the S-1 Executive Committee consisting of J. B. Conant, chairman; L. J. Briggs, A. H. Compton, E. O. Lawrence, E. V. Murphree and H. C. Urey, with H. J. Wenzel as technical aide and Irvin Stewart as secretary. These meetings were held at the Carnegie Institution and were regularly attended by Brig. Gen. L. R. Groves, head of the Manhattan District project, who was
charged with the heavy responsibility for erecting plants and producing uranium 235 and plutonium in usable quantities by the methods developed by the research groups of S-1. By May 1, 1943, the undertaking had reached the point where it could be taken over advantageously by the Manhattan District and the work of OSRD on the uranium project was terminated.

During the war about 60 members of the Bureau staff were engaged on the atomic bomb project. Some of its leading physicists, chemists and mathematicians were assigned to the Clinton and Los Alamos laboratories at the request of the War Department.

Early in the war a simple and highly effective chemical method was developed at the National Bureau of Standards for removing harmful impurities from uranium. This was used in all subsequent production of uranium. Similarly a procedure was developed for producing graphite practically free from boron. These contributions were of great value to the project, because some of these impurities were strong absorbers of neutrons and their effective removal was a prerequisite to the establishment of a chain reaction in a pile using normal uranium.

The Bureau also served throughout the war as a central control laboratory for determining the purity of the uranium and other products that were used in the project. Thousands of chemical and spectrographic analyses were made during the course of this work. Measurements were made of the radium recovered from the uranium ores. Methods for separating the uranium isotopes were studied. The alpha-particle counting method was developed to measure the change in the relative abundance of the uranium isotopes during separation processes. Yet the work was so closely guarded that the Bureau's participation in the atomic bomb project was not known to the members of the staff not associated with the undertaking.

The Graphite Problem

In the early consideration of the use of atomic energy for military purposes, one of the first proposals (by L. Fermi and L. Szilard) was to use graphite as a moderator in obtaining a controllable chain reaction for the production of plutonium. It was known that impurities which might be present in the graphite or uranium would capture some of the neutrons generated by fission of the uranium 235, probably a large enough proportion of them to prevent a self-sustaining reaction from occurring in a uranium-graphite pile. Thus the problems of procuring sufficiently pure graphite and sufficiently pure uranium were outstandingly important among the many assignments undertaken by the Bureau in connection with the atomic energy project.

While graphite was a common article of commerce, its usefulness had never been seriously affected by its impurities that now assumed such commanding importance. In January, 1941, L. Szilard and D. P. Mitchell of Columbia University came to the Bureau to discuss possible reasons for the discrepancy between the analysis of graphite ash made by a commercial analyst (by a spectrographic method) and the neutron absorption measurements of the ash by E. Fermi. It was concluded that the analytical results, for boron, in particular, were at fault. Hence, the first task was to devise a reliable method for the determination of boron in graphite, which was undertaken by C. J. Rodden.

The procedure developed, which became standard for the determination of boron in uranium compounds as well as in graphite, showed that much of the neutron absorption of the graphite ash measured by Fermi was due to boron.

With a reliable method for determining small amounts of boron as a guide, the next step was to find out the sources of this impurity. The graphite which was finally produced was much lower in boron than any previously examined. The new procedure was used to produce graphite for the first uranium-graphite pile, which was successfully operated in Chicago in December, 1942.

The Uranium Problem

A decisive step in the purification of uranium compounds was taken in the summer of 1941 at the Bureau, when Dr. J. I. Hoffman showed that uranyl nitrate could be separated from all harmful elements by extraction with
ether. By this method, sufficiently pure uranium could be obtained from crude uranium oxide and from pitchblende and carnation ore concentrates. The ether extraction process became the standard procedure for the final purification of all the uranium subsequently used in the piles.

Since metallic uranium had not been made hitherto in commercial quantities, it was necessary to develop methods for producing the metal, as well as to determine and control the purity of the materials used in its production. The investigation of both phases proceeded simultaneously. The preparation of uranium tetrachloride was begun by C. J. Rodden early in 1941. Soon thereafter fused pieces of metal were produced. In June, 1941, some of the pieces of metal thus obtained were remelted by J. G. Thompson and H. E. Cleaves. An important discovery resulting directly from this was that the melting point of uranium was lower by at least 600° than the recorded value of approximately 1800° C.

While the study of metal production was going forward, progress was also being made in the analyses of uranium compounds and in procedures for purifying them. Determinations of boron were now being made by E. F. Scrivner by special spectrographic procedures that were standardized by means of samples chemically analyzed by J. A. Scherrer.

During 1942, specifications for the purity of uranium compounds were prepared by a committee composed of C. J. Rodden, L. Sullard and R. Rosen, with F. H. Speeding as chairman. Methods of chemical analysis for many elements present as impurities were developed and hundreds of samples were analyzed at the Bureau by J. J. Tregoning and G. Petretic. For example, methods for the determination of rare earths in the impure oxide were of especial importance because of the known neutron-absorbing properties of certain of the elements in this group. K. D. Fleischer and J. I. Hoffman contributed materially to the solution of this problem.

In conjunction with H. Pochon of the Eldorado Gold Mining Co., a method for obtaining purer black oxide was found which consisted of an acid leach of the material. The NBS contracted for the treatment of future shipments and the working over of some of the older shipments by this method.

As a result of the experimental work at the NBS it was evident in August of 1941, that raw materials for satisfactory uranium metal could be obtained or produced. However, at this time there was only one producer of metallic uranium, Metal Hydrides, Inc., at Beverly, Mass. The boron content of the powdered metal furnished by this company was so high that it was practically useless for the purpose intended. In contrast with the metal first produced, with an excessively high boron content, the metal produced by Metal Hydrides after the Bureau’s assistance was satisfactorily low in boron.

The work covered a number of phases of the project besides those relating to the procurement and analytical control of materials used in the piles. For example, in the latter part of 1941, C. J. Rodden and J. I. Hoffman developed a method for the purification and preparation of uranium compounds suitable for making films for determining isotopic composition by alpha-particle counting techniques, developed by L. F. Curtiss.

The Central Control Laboratory

When in 1942 the Manhattan District assumed responsibility for procurement, the analytical work rapidly increased in scope and volume. Methods were now developed for the assay of uranium-bearing materials ranging from low grade carnation to high grade pitchblende.

In February, 1943, when the Manhattan District set up a program for all raw and finished materials connected with the production of the metal, the NBS was designated as the Central Control Laboratory. As an illustration of the complexity of some of the work, one product required 17 individual chemical analyses in addition to the spectrographic determination of 29 elements. To aid other laboratories concerned with the metal control program, standard analyzed samples of some fifteen materials were prepared, including four kinds of uranium ore. Guest workers were instructed in analytical methods and other laboratories and plants
operating under Manhattan District contracts were assisted in developing procedures and in overcoming difficulties.

Up to the end of 1946 nearly 9000 samples of materials had been received and nearly 30,000 separate analyses made. The developmental work on these problems of procurement resulted in contributions to 47 reports. In 1945, C. J. Rodden became chairman of the Manhattan District Analytical Committee.

As further examples of the diverse nature of the problems that came to the central control laboratory, the following are of interest:

1. In many cases uranium ores were purchased and paid for on the basis of their uranium content, with the provision that the radium be returned to the original owners in the residues left after removal of the uranium. Disagreements arose. To settle these, radium standards were prepared by L. F. Curtiss of the Radioactivity section for checking methods of determination of radium.

2. Owing to the fact that the Metallurgical Laboratory at Chicago did not have adequate facilities for analytical control in their early work, many materials involving special types of analyses were sent to the NBS. This included heavy water and the catalysts used in its production. Requests for assistance, especially in the capacity of consultants, continued through 1946.

3. In cooperation with W. N. Harrison of the Clay and Silicate Products Division, ceramic materials were examined for suitability for use in the electromagnetic process of isotope separation.

**Spectrographic Analyses**

The work of the Spectrochemical Laboratory on the atomic bomb project was initiated in April 1940 when tests of the purity of several uranium oxide samples were made by qualitative spectrographic analysis. When the supervision of work on uranium was later assigned to the Office of Scientific Research and Development, the volume of testing increased and the samples then submitted included a variety of uranium compounds and other materials of importance to the project. It was apparent at this time that the usual spectrographic methods of analysis were inadequate for the analysis of uranium especially in view of the increasing purity of the materials being produced.

The production of uranium of high purity was one of the serious problems encountered in the utilization of uranium as a source of atomic energy. Impurities, particularly the lighter elements such as boron, cadmium, and lithium, are effective absorbers of neutrons. Relatively small amounts of the impurities may reduce the efficiency of uranium fission below the point where a chain or self-sustaining nuclear reaction can be obtained. In order to control the production of pure uranium and to inspect the final product, methods of analysis were required for the determination of 60 or more chemical elements on a routine basis where speed, high sensitivity, and accuracy were important considerations.

The problems of the spectrographic analysis of uranium-base materials was complicated mainly by the highly-complex spectrum of uranium. Under the usual spectrographic procedures interference by uranium lines would have rendered spectrographic analysis ineffective for determinations of impurities at low concentrations. This was overcome by the development of four concentrational methods in which the impurities are separated from the uranium and then determined spectrographically.

The first satisfactory method for the spectrochemical analysis of uranium was developed at the National Bureau of Standards, and was described by E. F. Scribner and R. R. Mullin in April, 1942. It is physical in nature, involving fractional distillation of the impurities from a uranium oxide base. High sensitivity and accuracy were realized by adding a material, termed a "carrier," to the sample and distilling the carrier from the mixture by means of an electric arc. The carrier serves to sweep the volatile impurities into the arc, the light from which is observed by a spectrograph. The high sensitivity of the method is attained by the almost complete suppression of the spectrum of uranium.

The carrier-distillation method was improved by a series of controls, including an electrode assembly of novel design. In June
1942, the method provided for the determination of boron and cadmium down to the desired limits, and included the determination of arsenic, cobalt, lithium, manganese, nickel, silver and sodium. The elements now determined by the method are Ag, Al, As, Au, B, Ba, Be, Bi, Cd, Co, Cr, Cs, Cu, Fe, Ge, Hg, In, K, Li, Mg, Mn, Mo, Na, Ni, Pb, Pb, Rb, Sb, Si, Sn, Tl, and Zn. The basic method was modified for the more accurate determination of iron, magnesium and manganese in February 1945, thus obviating the need for chemical determinations of iron and manganese. The carrier-distillation method was adopted by other laboratories on the project and applied in the analysis of thousands of samples of uranium and similar materials. Over 120,000 determinations were made at the Bureau during the years 1945-46.

The three remaining methods that were devised for the analysis of uranium-base materials provide for the determination of the less-volatile impurities to which the carrier-distillation method does not apply. The spectrographic methods involve the analysis of three chemical concentrates from uranium-base samples. These concentrates, prepared by the chemical section under the supervision of C. J. Rodden, include the rare-earth group (Ce, Dy, Er, Eu, Gd, Ho, La, Lu, Nd, Pr, Sc, Sm, Tb, Th, Tm, Y and Yb), the platinum-metal group (Ir, Pt, Rh and Ru) and a group of elements precipitated by cupferron (Cb, Ga, Hf, Pd, Ta, Ti, V, W, and Zr). The required sensitivity of test was obtained by the combined chemical and spectrographic procedures and in some cases a remarkable limit was achieved.

The complete system of spectrographic methods for the analysis of uranium-base materials was recently described by Scribner and Mallin.

**Metallurgical Investigation of Uranium**

Phases of the metallurgy of uranium investigated at the Bureau included the development of methods for melting and casting the metal, methods for working uranium, and investigation of the uranium-oxygen system which necessarily included development of methods for determining oxygen in uranium and for metallographic examination.

Investigations on thorium included a few experiments on comparison of beryllia and thorium as metal pastures for the metal, determination of density and hardness, development of procedures for preparing metallographic specimens and study of the microstructure of cast and extruded thorium.

Melting and casting uranium. In the early stages of the project, utilization of uranium required the development of methods for melting and casting.

Investigation of the melting of uranium was initiated at the Bureau in May 1941, using metal prepared by C. J. Rodden. Work on the problem was sporadic until April 1942 when metal from contract producers became available and extensive research on the metallurgy of uranium began. Contributions of the Metallurgical Division to the technique of melting uranium included (1) demonstration that uranium could be melted successfully and without contamination, using beryllia crucibles, and (2) development of methods for fabricating uranium: The hot and cold working properties of uranium were investigated and procedures for forging, rolling, swaging and wire drawing were developed.

Other metallurgical research included the determination of the solubility of oxygen in molten and solid uranium; determination of oxygen in uranium by vacuum fusion; reactions of uranium with oxygen and nitrogen at temperatures up to 500°C; and metallography of uranium.

**Physical and Mechanical Properties of Uranium**

Much of the information in the literature on the properties of uranium was inaccurate because it represented the properties of the impure metal previously available and not those of the relatively pure metal produced by methods developed recently.

Early melting point experiments in the Metallurgy Division at the Bureau showed the melting point of uranium to be much lower than the value of about 1850°C that was given in many handbooks. The metal available in 1942 melted in the range 1076 to 1125°C.
Precise melting point determinations were later made by the Heat and Power division on four specimens of uranium produced late in 1943.

Other properties determined in various laboratories of the Bureau include: Density; electrical resistivity and temperature coefficient of resistance; thermoelectric potential; specific heat of uranium and its compounds at high temperatures; transformation points; hardness, tensile properties; compressive properties; and physico-chemical data on uranium compounds.

The First Spectrum of Uranium

At the beginning of the year 1942 there were only fragmentary descriptions of the spectra emitted by neutral and ionized uranium atoms. No Zeeman effects had been observed; no term analyses had been made; nothing was known of the configuration of the valence electrons; and no value had been found for the nuclear moment of the odd isotope. It was known, however, that the emission spectrum observed in the ordinary arc and spark sources is exceedingly complex, and does not at all resemble the spectra of chromium, molybdenum, and tungsten, which precede it in the periodic table of the chemical elements.

A much clearer understanding of the structure of the uranium atom was necessary in connection with other investigations that were underway, and W. F. Meggers and C. C. Kees of the Spectroscopy section undertook an investigation of the uranium spectra.

The program of work comprised the observation of the uranium spectra as emitted by arcs and spark discharges in air at normal and at reduced pressures, by discharges in magnetic fields, in hollow cathodes, and by under-water spark discharges. Available for making the observations were four concave-grating spectrographs and a large quartz-prism spectrograph, together with auxiliary apparatus such as Fabry-Feret interferometers and Lummer-Oehrcke plates.

A separation was effected of the lines emitted by neutral uranium atoms from those emitted by ions. A list of more than 9,000 lines with accurate wavelengths, wave-numbers, and estimated intensities, for the region 3,000A-11,000A, were compiled as descriptive of the spectrum of the neutral atom. A partial analysis of this spectrum was made by the classification of about 2,000 lines as combinations between 18 low and metastable odd energy levels with more than 28 higher even levels. On the basis of well-resolved Zeeman effects several of the low levels were identified as components of 5L, 5K, 7M, and 7K terms arising in the electron configurations r^3d^2 and r^3d^2s. The spectrum of uranium was interpreted as that of a rare-earth element analogous to that of neodymium, uranium being designated as the third member of a second group of rare-earths beginning with thorium. Easy ionization in the electric arc and in magnetic fields, and the short-wave limit of the observed spectrum indicated that the ionization potential of uranium atoms is approximately four volts.

Concentration of Isotopes

During the summer of 1941, A. Keith Brewer and S. L. Madorsky developed a reflux electromigration method for the concentration of isotopes. The mechanism presupposes the existence of slight differences in the transport velocities of isotopic ions in solution. The basic principle involved in the process is the establishment of the conditions of counter-current reflux between the isotopic ions migrating in one direction in an electric field and a stream of electrolyte flowing in the opposite direction.

A difference in the transport velocities for isotopic ions had been postulated as early as 1921 by Lindemann. Numerous attempts by Kendall and his co-workers in which ions were electrolyzed through long columns of agar failed to detect a separation effect. It was not until the counter-current electromigration method was developed at the National Bureau of Standards that a separation of potassium isotopes based on ion mobility differences was realized.

Molecular Distillation

The term molecular distillation has been applied to that type of distillation where there is no exchange between the escaping vapor and the evaporating surface. This is accomplished by operating at such low pressures that the mean free path of the escaping molecules is of the order of the distance
between the surface of the evaporating liquid and the cooled condensing walls of the still. Brewer, Madorsky, and Westhaver developed a new type of molecular still in which any desired number of single-stage stills are so connected together that the resultant separation realized in one operation is equal to the separation per stage raised to the power of the number of stages. All transfer of material between stages takes place automatically by gravity feed. As a result, the labor involved in a multi-stage system is cut to little more than for a single-stage operation. In addition, the quantity of material required as well as the time of operation is reduced to such an extent that the method becomes an efficient process for the separation of isotopes.

The first type of still developed by Brewer, Madorsky, Westhaver, and Taylor was of the high platage all-gravity feed design. Numerous modifications of the same general design were tested. The most successful design consisted of a long glass tube indented along the bottom at regular intervals to form shallow pools. A water-cooled copper tube to which copper condensing plates were attached was then inserted in the glass tube in such a manner that the liquid evaporating from each tube condensed and dropped into the next highest pool. The entire assembly was placed on an incline of about 5° so that the liquid spilled back from pool to pool equal in amount to the quantity evaporating.

The second type of molecular still was developed by S. L. Madorsky. It consisted of a number of vertical cells arranged in series in such a manner that counter-current reflux is maintained throughout the entire group. Special magnetic lift-pumps were designed to supply the feed between cells.

Mass Spectrometer Analyses

At the outset of the war, the National Bureau of Standards did not have a mass spectrometer laboratory. When the electrolytic migration method for the separation of potassium isotopes was devised, it was necessary to set up at the Bureau the mass spectrometer which had been built at the Fixed Nitrogen Research Laboratory by A. K. Brewer to make the analyses. This marked the beginning of the present Mass Spectrometry laboratory. During the time that the electromigration method was being investigated, the mass spectrometer was run about 16 hours per day.

A mass spectrometer was designed to analyze uranium in the form of gaseous UF₆. This gas upon ionization by electron impact in the mass spectrometer is dissociated into all possible combinations of uranium and fluorine. The original method of operation consisted of reading the two mass peaks simultaneously. In order to enhance the sensitivity of the instrument, the entire electrical pick-up for the reference peak was replaced with a more stable design while the circuit for the other peak was revised and reinsulated. While these changes materially improved the stability and sensitivity of the instrument, the actual recording of data was still cumbersome since it was impossible for one observer to read the deflections for both peaks at the same time. In addition to reading the meters, the operator was required to operate the voltage scanning dials by hand to bring into focus the mass peaks.

In order to simplify the operation of the mass spectrometer as well as to increase the accuracy of observation, an automatic voltage sweep and recording mechanism were designed. The recorder was assembled from parts of commercial Brown instruments. The scanning circuit was a modification of that used on the Consolidated mass spectrometer, in that the accelerating voltage was changed by allowing the potential on a condenser to decay through a high resistance. When the potential had changed over the required range, a relay arrangement allowed the condenser to be recharged and the process repeated. To eliminate all manual recording of data during a run, a control was placed in the ionizing circuit which permitted the operator to keep the reference isotope beam at a constant value. This recorder not only vastly simplified the operation of the mass spectrometer but also increased the precision and shortened the time of analysis.
Radioactivity Measurements

In the early part of the development of the atomic bomb it was necessary to have a method of testing various procedures for separating the isotopes of uranium. In particular, it was desirable to be able to make measurements which would reveal to what extent the percentage of uranium 235 had been increased in a sample by the particular treatment in question and to detect very small increases in this percentage. This permitted the efficacy of various proposals for this isotopic enrichment to be tested at the early stages and thus permit a selection of the best, with a minimum loss of time.

A method was developed by L. F. Curtiss in the Radioactivity section based on the rate of emission of alpha particles from the sample of uranium, using the alpha particles from the uranium 234 isotope as an indicator. Since the percentage of enrichment for the 235 and 234 isotopes depend on their masses relative to the mass of the third, the 238 isotope, any treatment which enriches 235 will also increase the amount of 234 in a simple ratio of the masses. However, in the natural sample there are just as many alpha particles from 238 as from 234 because the 234 is produced from 238 and the process has been going on in nature a sufficient time for the amounts of each to reach a steady value. If the relative amount of 234 is increased, and with it the relative amount of 235, there will be more alpha particles per gram per second from the enriched sample than from a natural untreated sample. This method was made sufficiently accurate to detect a change of 1/10 percent in the enrichment. To do this at least 1,000,000 alpha particles must be counted reliably and accurately from each sample.

Equipment to do this work was developed and constructed in the Radioactivity section and numerous samples were tested for various laboratories, which aided greatly in selecting suitable methods of enrichment. In particular, the measurements made at the NBS were very helpful to P. H. Abelson at the Naval Research Laboratory in the development of his process for isotopic separation.

As a by-product of the work in counting alpha particles from uranium the Radioactivity laboratory prepared many carefully weighed samples of uranium deposited in accurately formed discs on platinum. These samples constitute a reliable source of beta-rays which can be used as standards in the calibration of beta-ray counters. Sets of these standards were furnished various laboratories engaged in radioactive work in connection with the war.

In connection with radioactive war-work, it became desirable to have many Geiger-Muller counters available which had the thinnest possible aluminum walls, so that they could be used to measure beta-rays. Previous methods of producing such counters were slow and expensive. The Radioactivity section developed a method of copper plating thin aluminum toothpaste tubes so that fittings could be attached to them by ordinary soft solder to convert them into Geiger-Muller tube counters. The operation was very simple and cheap so that several counters could be made in the time previously required to make one, with a corresponding reduction in cost. These toothpaste tubes also had the minimum thickness required for evacuation and filling without collapsing the tube.

For the identification and estimation of radioactive isotopes which emit alpha rays it is desirable to have a counting equipment which will separate the particles of the same range characteristic of each isotope and count them separately. An electronic circuit was developed which would register the pulse produced by the amplification of the ionization resulting from a single alpha particle of a given range. All other pulses were rejected by this particular circuit. By arranging a sufficient number of these circuits adjusted so that they just covered the various sizes of pulses to be anticipated, the actual distribution of the alpha particles in terms of their ranges from a particular source could be found.

One of the problems in the procurement of uranium ore was the determination of the quantity of radium in the ore as well as the quantity of uranium, for both these elements determine the value of the ore. This problem
3. The Air Burst Proximity Fuze

One of the most spectacular of the weapons developed during the war, and one whose existence the Allied Command guarded most closely, was the radio proximity fuze—the fuze which automatically explodes a projectile, be it shell, bomb, rocket, or mortar, approximately at the point at which the most damage will be inflicted.

The idea of a fuze which will explode when it is close to a target is an old one in ordnance circles. The advantages are obvious. If a fuze can be made to explode anywhere in the vicinity of an airplane target, the effective size of the target is greatly increased and fewer shots are wasted. Many projectiles which miss the airplane would explode close enough to destroy it.

When projectiles are used against ground targets, such as infantry, the advantage of air burst is equally great. With a contact fuze relatively shallow foxholes or slight depressions in the ground provide good protection from all save direct hits. It is again obvious that if the projectile could be made to explode say 20 or 30 feet in the air, even deep foxholes would afford scant protection to enemy troops. Furthermore, destruction of buildings by the blast effect is considerably enhanced with the air burst.

The VT (variable time) fuze, therefore, is a weapon of almost overwhelming possibilities. Projectile effectiveness (casualties per round) is increased from five to twenty times that of the same projectile fitted with a contact fuze. To realize completely the importance of this, we must consider, in addition to the increase in enemy casualties, the all-important problems of logistics—the movement of men and supplies. One squadron more than does the work of five; less than one-fifth of the usual amount of supplies (food, ammunition and all the sundries) are required for a particular operational use. These advantages are so great that they warrant almost any degree of expenditure and effort to perfect the VT fuze and to supply it in quantity to our service forces.

Bombs were not a very important weapon in the First World War because of the limited use of airplanes. In the Second World War, they were of first importance. Here the need for VT fuzes was urgent. One startling use of VT-fuzed bombs was to neutralize antiaircraft gun positions by putting the gun crews out of action or by forcing them to seek cover, so that other bombers could attack without opposition. Applications other than on fragmentation bombs are apparent, such as use on large blast bombs, and fire bombs.

Rockets are one of the most important new ordnance items used in the recent war. Their widespread use resulted in urgent demands for proximity fuzes for these projectiles.

There is no weapon to which the VT fuze is more suited than the trench mortar—the foxhole cannon—none in which the gain in effectiveness is higher. The VT principle was not applied to mortars early in the war because development had not progressed to the point where sufficiently small fuzes could be made. Development was complete at the war's end and large-scale production was well on the way. The final model was less than half the size of the smallest previous fuze.

The radio proximity fuze is a tiny radio sending and receiving station and is so small that some models may be covered by a man's hand. It operates by continuously sending out radio waves which act as feelers, reaching out to detect any nearby object. When an object of reasonable size is approached, the radio waves reaching that object are reflected back to the projectile. The fuze receiver picks up these reflected waves, and when they reach a sufficient intensity (that is, when the projectile is close enough to the object), they operate an electronic switch that detonates the fuze and the projectile.

VT fuzes so far developed are all generally similar in that they have corresponding elements. There are many major differences, but they involve such factors as site, shape, detailed circuitry, safety means, and the type of electric power supply.
was solved by utilizing the technique of radon measurement, developed for another purpose, in which alpha particles are counted.

During the war, plants were established by the Army and Navy for applying radium luminous compounds to dials of instruments. The application of such compounds can result in serious injury to personnel unless proper regulations and tests are established. The measurement of radon in the exhaled breath of radium dial painters was thus mandatory. The Radioactivity section of the Bureau was instrumental in the development of suitable regulations and made the tests of expired air to determine the efficacy of these regulations and their enforcement. In addition to the apparatus for determining the radon content of samples of air the NBS designed a glass bulb for shipping samples of air which could be sent evacuated to the collecting point to facilitate the transfer of the sample to the flask. This service for the Army and Navy was of considerable value to them, since without it they would have hesitated to engage civilians to apply radium luminous compounds and expose them to the well known dangers of radium poisoning. As a result the hazards have been reduced to a few cases of temporary over-exposure.

The same general equipment used for measuring breath samples was also used to measure radium in uranium ores. The chief difference in the procedure is that, for measurement of radium, the ore sample is dissolved and the radon accumulated in the solution over a definite time. The radon is then transferred to the counting chamber where the alpha particles are counted. From this procedure the amount of radon is determined. From the amount of radon and the time during which it was accumulated the amount of radium in the sample can be computed.

Several thousand such measurements were made. As a part of the program, comparative measurements were made with other laboratories which carried out determinations for various contractors. As a result it was found that the values obtained by the Bureau were both more consistent within themselves and nearer the average values of all other laboratories. This resulted in the selection of the Bureau as a referee in case of disagreement of measurements made elsewhere.
Early Development

On June 27, 1940, the National Defense Research Committee was organized as an agency to encourage, promote, and coordinate national military research.

In the original NDRC organization, Division A, Armor and Ordnance, under Dr. R. C. Tolman, had the responsibility for development of new and improved ammunition. Dr. C. C. Lauritsen, Professor of Physics at the California Institute of Technology and Vice Chairman of Division A, devoted a large part of his energies to initiating development of proximity fuses. Such development was first begun in the United States at the Department of Terrestrial Magnetism, Carnegie Institution of Washington in August 1940, under NDRC.

In November 1940, Dr. Tolman and Dr. Lauritsen discussed with Dr. L. J. Briggs, Director of the National Bureau of Standards, the problem of fullest utilization of the facilities of the Bureau. As a result, Dr. Alexander Ellett, formerly Professor of Physics at the State University of Iowa, was designated NDRC liaison officer to the Bureau of Standards. Dr. Ellett was shortly appointed chairman of a newly organized section, Section E, of Dr. Tolman's Armor and Ordnance Division of NDRC. This section was made responsible for development of radio proximity fuses for nonrotating projectiles. The work on a radio proximity fuse for rotating projectiles remained at the Department of Terrestrial Magnetism, under Dr. H. M. A. Tuve, as Section T of Division A, NDRC.

On December 26, 1940, Dr. Ellett enlisted the interest and services of Harry Diamond, of the National Bureau of Standards, and work was begun at the NBS on the development of the radio-operated proximity fuse. This work was centered in the Radio section, which was headed by Dr. J. H. Dellinger.

Development work started much earlier in other countries. Great Britain was working on the idea in 1937 and in mid-1940 sent to this country a commission which gave American scientists the benefit of their experiences. Germany started work on similar devices in the early thirties. Difficulties lay, not in formulating the basic ideas which had been proposed by a number of people before the war, but in the determination of basic design data. This involved answers to such questions as how strongly do airplanes and other targets reflect radio waves, what is the detailed form of the signal, what degree of responsiveness can be obtained from radio circuits, and how can that responsiveness be shaped to obtain best fuse operation. Determination of mechanical design detail and the development of tiny yet very sturdy electrical and mechanical components capable of performing under the severe conditions of war were of equal importance.

From the beginning of work on radio proximity fuses, the prime requirement was speed. These projects required the successful completion of a tremendous amount of investigation in various scientific fields, in a minimum of time and necessitated continuous expansion of the scientific staff engaged in this work at the Bureau. The nucleus of this staff was formed in early 1941, from members of the NBS staff and, subsequently, many other NBS scientists were loaned by various divisions to the fuse project. Scientists and technicians were brought in from university and commercial laboratories all over the country. Beginning with a staff of eight in early 1941, the fuse development group at the Bureau grew into an organization of 400 in 1945.

The first object of bomb fuse development was to build a fuse to set off a rocket attached to a bomb after that bomb had fallen to within several hundred feet of a battleship. By this means, impact velocities high enough to penetrate and sink a battleship were expected. This requirement served as the first short-time objective, but it quickly gave way to a more general proximity fuse development program.

Mr. L. V. Berkner, of Carnegie Institution, had been working on proximity fuses at the Department of Terrestrial Magnetism Laboratories. He supplied the general introduction to the project, proposing a beating oscillator arrangement. Experimental work on this and other proximity sensitive radio circuits was commenced. Later it was learned that British scientists were experimenting with a reaction oscillator using plate
detection, and work was under way at Carnegie Institution on a similar arrangement.

It was soon apparent that a fuze utilizing the Doppler effect of reflected radio waves was the most promising. W. S. Himan, Jr., and H. Diamond of the NBS Radio section devised a diode detector arrangement whereby any reflected radio wave caused variation of the radio frequency currents in an antenna to produce the desired signals, and a series of laboratory experiments were undertaken. The first model was tested by being raised and lowered over the ground by ropes and pulleys. Signals reflected from the ground were measured and found to be strong enough to promise successful operation.

The model was taken to the NBS field station at Meadows, Maryland, about January 15, 1941, and a private pilot, who was not informed of the nature of the experiment, flew over the model, which was fixed at the top of an 84-foot radio tower. When the plane passed within some 50 feet of the model, indication of its passage was observed. As a result of this test, numerous other tests of this nature were conducted at the Naval Proving Ground at Dahlgren, Virginia. Models from the Bureau, as well as models from the Department of Terrestrial Magnetism, were used. These tests gave the first positive operational information on certain design details which were later used in VT fuzes for antisubmarine operations.

Later, R. D. Huntoon, of the NBS staff, supervised an extensive series of tests at the Naval Air Station at Lakehurst with the cooperation of Naval personnel at that station. Fuze models were suspended beneath a blimp and fighter planes dived past the models. Photographs taken of the form of fuze signal provided information which was of major importance in the design of fuzees for antisubmarine use.

During January of 1941 in an experiment at the Meadows station, a VT fuze model was carried aloft by large meteorological balloons (tethered) and the balloons shot down with a .22 calibre rifle. The model was released at an altitude of about 300 feet and functioned by detonating a test charge at about 40 feet above the ground. Models built for preliminary operational trials were mounted in M38 practice bombs and on February 12, 1941, were dropped from a plane flying at 3,000 feet at the Naval Proving Ground at Dahlgren, Virginia. Two of these models operated after about 8 seconds of fall, but the third functioned properly about 10 feet above the water target. A second set of three models was then constructed and tested in the same manner on March 27, 1941. Similar results were obtained.

The mechanical design was then changed and new models were made. Six of these were tested at the Naval Proving Ground at Dahlgren, Virginia, on April 28, 1941. With the bomber flying at 3,000 feet, the six bombs were released separately. All six functioned at heights of from 150 to 300 feet over the water; these heights corresponded to the measured responsiveness of the fuzees as determined in the laboratory.

These tests were a strong factor in determining the course of proximity fuze development because they proved that a radio proximity fuze was practical. Up to the date of these tests, a large amount of effort was being expended in various agencies on the development of other proximity fuze principles, notably the photo-electric (a successful development, treated later) and the acoustic fuze. These were relegated to second place as the success of the radio fuze became assured.

Having demonstrated the practicability of the principle, it remained to add the detailed engineering and development work needed to turn a "first model effort" into a producible item fitting all of the service requirements. While these first models proved the principle, they did not provide all of the components or practices required to produce a satisfactory service fuze. At this stage the real work had just begun.

Model construction, however, was based on a principle which was adopted for all VT fuzees. All components were rigidly mounted. Circuit elements were either completely immersed in wax or were tied to a rugged frame structure and given a heavy protective wax coating. Shock mounting was not used, and the principle of making all components so stiff and rugged that there could be only minute relative motion, even with severe
mechanical vibration, is still in general use.

In about June of 1941, work was extended to include the development of rocket fuzes. Rockets available at that time were of British design built for the defense of London. The complete round was about seven feet long and 3.25 inches in diameter. The initial design for this round placed the fuze between the rocket motor and the high explosive. Except for the size of the fuze occasioned by the large commercial batteries and by the size of the tubes and components, the fuze was reasonably good.

During these early months of development, primary attention was directed toward the electronic circuits and principles. When these were reasonably well established, intensive work was started on the mechanical switches and safety mechanisms which played such an important role in the production of the complete fuze. Scientists and engineers drew heavily on the broad knowledge of explosives and safety mechanisms of Army Ordnance experts, and then devised the specific designs. Development and testing of bomb fuzes was continued during the same period.

The electronic tubes were of particular importance, the commercial types then available being both large and structurally weak. Small hearing aid tubes offered the best solution to the problem. The Raytheon Manufacturing Company, Hygrade Sylvania, the General Electric Company, and the Hytron Manufacturing Company, who were already working on tubes for the shell fuze under Section T contracts, were consulted, and a development program was begun which finally resulted in the production of very large quantities of high quality, small, and extremely rugged tubes for VT fuzes. Cledo Brunetti headed a group which collaborated in the development. Some idea of the difficulties these manufacturers met and solved may be had by a one-sentence description of the mounting of the tube filament—"Working so fast that observation is difficult, young women put invisible wires into invisible holes and weld them in place."

In February of 1942, a new method of arming VT fuzes was proposed and tested by the Bureau staff—RC, or condenser, arming. An electric charge was fed into a condenser through a resistor to provide delay in the charging time. The time delay was controlled by the size of the resistor and condenser. Circuits were laid out so that when a predetermined time had elapsed, the condenser had sufficient electric charge to furnish the current for exploding the detonator when the fuze approached the target. The system was immediately used for tests of sample lots and was later adopted and used in many fuzes, including the VT shell fuze.

During May 1942, a few bomb fuzes were built using an arrangement which later became one of the most successful types. The bomb body was not used as the antenna, but two strong metal bars were built into the fuze and mounted at right angles to the fuze and bomb axis, thus providing an antenna separate from the bomb body. These were first tested on May 18, 1942, at Dahlgren, Virginia.

In this same period, C. H. Page started work on a simplified oscillator employing grid detection and pursued it later with the collaboration of Andrew Stratton of the staff of the Royal Aircraft Establishment of Great Britain, who had also done earlier work on the circuit. The work culminated in the general adoption of the circuit for bomb, rocket, and mortar fuzes.

Fuzes development continually encountered testing problems. Tests under conditions simulating flight conditions were very valuable in development and production, but were never finally conclusive. Field testing is a "one try" proposition, since each test destroys the fuze. Evidence was obtained on a statistical basis, literally thousands of test rounds being required to establish fuze quality or to examine and determine the cause of some defects. Extensive statistical studies were required, and a group of statisticians under the direction of T. N. White was established as part of the Proof Operations section, and later as a separate section.

The Fuze for the M-8 Rocket

On May 12, 1942, the Army requested Section E, Division A, NMC, and through them
the National Bureau of Standards, to develop a VT fuse for a new Army 4.5-inch airborne rocket, the M-6. The project was given top priority, there being an urgent need for the weapon to combat the then powerful German Luftwaffe. Various expedients were adopted to rush completion of samples for testing. Complicated mechanical and plastic parts were fabricated by hand to avoid the delay incidental to procuring tools and molds for high speed production. Temporary switch and safety mechanisms were used. Batteries too large for final use were available and these were used until battery development was complete.

The final design consisted of three primary parts; the fuze head, containing the electric circuits; a new and quite small dry battery developed by the National Carbon Company for the shell fuze; and a switch, interrupter, and booster mechanism. The original design of the switch and safety mechanism was developed by W. B. McLean and J. Rabinow of the NBS staff and remained virtually unchanged throughout the model and production stages. The safety record throughout the proof-testing period was remarkable, there being no instance of failure of the safety mechanism. Credit is due Globe-Union, Inc., of Milwaukee, manufacturer of the switch, for their excellent design detail work and for the perfection of their production methods.

Production of small proof lots was begun. The increased responsibilities inherent in the new development required new proving-ground facilities, and the South Atlantic Coast was surveyed for proving ground areas. A suitable area was found just south of Fort Fisher on the Coast near Wilmington, North Carolina. Test operations were started there in June 1942. L. S. Taylor, head of the Proof Operations Section at that time, supervised setting up the field station and the necessary laboratories, targets, and range accessories. These facilities included extensive photographic equipment for determining projectile and fuze performance.

To test the radio fuses, a rocket projector (gun mount) was set up at Fort Fisher on a tower about 30 feet above a level sandy area. Some 700 feet ahead of the projector, a wire screen 12 feet wide and 60 feet long was set up 20 feet above the level sand area. When the projectile was fired over this range, the fuze functioned only on approach to the wire screen, since this was the only object on the range whose distance with respect to the projectile was changing.

Nearly all of the development testing of the fuse for the 4.5-inch rocket was done on a range of this type. Various improvements were made. The height of the tower mounting the rocket projector was increased; photographic facilities were provided on the projector tower and the target was changed from a flat screen sheet 20 feet above the ground to a wire target of the shape of a medium bomber 60 feet above the ground. This arrangement proved to have the constant characteristics needed for the fuze development. It was useful in all kinds of weather. While with the old aerial targets, 12 test rounds per day was a good average, a round a minute was possible with the ground target.

More than 1,000 fuzes were built in the Bureau's model shops during June and July. Field tests were quite satisfactory; almost all of the rounds passing within 60 feet of the target exploded alongside.

Seven manufacturing companies were asked to accept OSRD contracts to develop production designs and produce the fuzes. Complete production designs were drawn up and full production was started without waiting for initial model trials. It will be recognized that any such procedure is a gamble, since first engineering designs are seldom perfect. However, the urgency of the project did not permit the slow-but-sure policy of testing new models completely prior to production.

Two markedly different fuzes were developed simultaneously for the 4.5-inch rocket, the radio fuse and the photoelectric fuse. The latter was developed by a group headed by J. E. Henderson and later by A. V. Astin of the NBS staff. The fuze was one of the first successful types developed. Mention of its use has been omitted up to this point because properties inherent in this fuse prejudiced its operational use.

The photoelectric fuse is sensitive to changes in light intensity. It is a photoelectric cell equipped with a lens. When an
THE AIR BURST PROXIMITY FUZE

About 400,000 each of the radio and photo-electric proximity fuzes were manufactured.

While the radio proximity fuze was developed primarily for use against aircraft, the design proved correct either for use from airplanes against troops and gun emplacements, or for use from the ground against such targets. One spectacular application was its use as a barrage weapon from large tanks. A multi-barreled projector holding 80 VT-fuzed 4 1/2-inch rockets was mounted on a General Sherman tank. The rounds were fired at one-tenth second intervals. Operation was excellent, and the ground target area was completely covered by a dense pattern of fragments from the exploding projectiles. Such concentration of fire makes any position without cover untenable.

In December 1942, the NBS Ordnance Development division, under the leadership of Harry Diamond, was organized and began functioning as a separate division of the Bureau, devoting its entire time and energy to the development of these fuzes.

**Bomb Fuze Development**

Upon the successful completion of the rocket fuze developments and transfer of procurement of rocket fuzes to the Signal Corps, the Ordnance Department requested Division 4, NDRC, in January 1943, to undertake the development of a similar fuze for possible use in air-to-air attacks on enemy bomber formations. This fuze was to fit in the same fuze well as standard nose fuzes and to protrude no more than 5 inches from the bomb. Initially, the tactical situation was considered in which the attacking plane flies above the enemy formation and releases the bomb while flying at the same speed and in the same direction as the formation. As the war progressed, however, it became evident that targets for such weapons were becoming scarce, and that such a weapon, if disclosed to the enemy, might be used more effectively by him than by Allied Air Forces. Accordingly, in May 1943, the request for bomb fuzes for air-to-air use was changed to one for fuzes for air-to-ground use to provide an air burst over-personnel and light material.

Object passes between a portion of the lens and the sky, the light intensity changes and the fuze detonates the projectile. Functionally, the fuze was excellent. Under conditions favorable to its use, nearly all of the fuzes tested functioned properly. Two faults inherent in this type, however prejudiced its service use and ultimately resulted in suspending further development work: (1) the fuse depended on light for operation and could not be used at night, and (2) when the sun moved into and out of the lens, the fuse functioned prior to reaching the target. Methods for resolving both difficulties had been devised and tested, but the radio fuzes were working so well that the project was eventually suspended in order to concentrate all available effort on that fuze.

Difficulties in developing and testing the radio proximity fuze were relieved by two simultaneous developments: (1) R. D. Huntoon, NBS staff member, devised highly selective fuse circuits using feedback principles, which are used in all present bomb, rocket and mortar fuzes, and (2) a method of using a fixed ground target was found. At this point it is relevant to point out that VT fuzes are not activated by objects whose distance from the fuze does not change, as, for instance, an object moving parallel to the fuze projectile and at the same velocity. From this it is obvious that if the VT fused projectile is made to travel parallel to a level plane, it will not operate on that level surface; it must approach that surface to function.

Under agreement with the Army Ordnance Department, the Signal Corps handled the procurement of all of the rocket fuzes and a substantial portion of the bomb fuzes which followed, and they maintained resident engineers and inspectors in the factories throughout the contract life. An extensive quality control laboratory, with equipment to provide a critical analysis of the fuzes, was set up at Belmar, New Jersey, in November, 1942, and continued through August, 1945, at which time the activity was transferred to the National Bureau of Standards.

Production was started in the latter part of 1942 and continued through most of 1945.
targets. The major share of attention for the ensuing year was devoted to this problem in its varied aspects.

Certainly design considerations were evident in the initial survey of the bomb fuze problem. Because the vehicle on which the fuze is mounted is different and the application is different, the electronic circuit must be different from that of the rocket fuze. The space into which the fuze must fit was also different, and a physical redesign was necessary. Since a bomb is not subject to setback at release, as is a rocket fuze, a different arming mechanism was necessary.

Experience in the development of the first rocket fuze demonstrated that the usual type of dry battery was not very satisfactory as a power source. It deteriorated rapidly in storage, its life being about a year under ideal storage conditions and not more than one or two months under conditions of high temperature and humidity. Dry batteries will not work at the sub-zero temperatures encountered by high-flying bombers.

Storage and reserve types of wet batteries were investigated in some detail. D. N. Craig and J. P. Schrodt of the NBS Battery section devoted much time to the project. The National Carbon Company built a number of samples of wet batteries which were energized by rocket acceleration, some of which performed reasonably well, but they had numerous faults which made them unsuitable for service use.

A wind-driven vane employed for arming leads naturally to a solution to the power supply problem. Since there is already a rotating system present, this may be utilized to drive a generator which supplies the necessary electrical power for the fuze. This arrangement was suggested by Harry Diamond and A. S. Clark, Technical Aide to Division 4, NDRC.

The requirement for a generator of small size, high power output, rugged design, stable operation and simple construction led to the development of a permanent magnet alternator. The rotor consisted of a very strong but small disc magnet made of Alnico. Coils were mounted on a magnetic stator surrounding the rotor. The original models of the generator were about 2 5/8 inches in diameter and 1 inch long. An electrical regulation circuit maintained constant generator power output even though the rotational speed of the generator varied over a range of three to one.


In April 1943, the Zenith Radio Corporation was asked by Division 4, NDRC, to make a production design of the fuze generator, and samples were received a few weeks later. These samples were somewhat smaller (3/4 in. long by 2 5/8 in. in diameter) than the original design and proved highly satisfactory. This design was subsequently used in large quantity in fuze manufacture.

Rectifiers were needed to change the alternating current developed by the generator to the direct current required by the fuze. Investigating commercial products, selenium rectifiers promised the best solution. The General Electric Company of Lynn, Massachusetts, the Federal Telephone and Radio Company of Newark, New Jersey, and P. R. Mallory Company of Philadelphia, Pennsylvania, and Indianapolis, Indiana, developed mass-production methods whereby millions of selenium rectifier discs were produced. Joseph Kaufman, special assistant to the Ordnance Development division, collaborated in the design and procurement of these rectifiers. The fuse rectifier assembly is about half the size of a cigarette.

Design considerations required generator speeds up to 80,000 rpm. At such speeds, mechanical stresses and the resulting vibration are great. Much effort was devoted to bearing design, to balancing the rotating mechanism, and to improving the rotor structure so that it would not fly apart at such high speeds. These problems were solved and the wind-driven generator was accepted as the standard power supply for VT bomb fuzes.

Small-scale production of models was begun at the National Bureau of Standards under the direction of C. H. Page, and a field test program was set up at Aberdeen Proving Grounds, Maryland, by the Ordnance Department. Design difficulties were corrected
during the ensuing months, and in May 1943, Division 4, NDRC contracted with the Zell Corporation of Baltimore to set up a pilot line. In August 1943, excellent field scores were consistently achieved with pilot line models when mounted on 500-pound bombs, dropped from 10,000 feet.

The Army Ordnance Department then requested that the fuze be designed to operate on all standard bombs from 100-pound to 1,000-pound sizes. An extensive investigation showed that the various bombs exhibited marked variations in their radiation properties. It was found, however, that by making two fuzes, one for the smaller bombs and another for the larger bombs, the range of bomb sizes could be satisfactorily covered and good performance achieved on each bomb. The fuze initially developed served, with a slight modification for one group of bombs, and a second fuze was designed for the other group of bombs. In late 1943 Bowen and Company, of Bethesda, Maryland, was asked by Division 4, NDRC, to set up another pilot line for the second fuze, and soon afterwards the Emerson Radio and Phonograph Corporation was asked to undertake large-scale manufacture of this model.

In the early stages of manufacture, as in the early stages of preliminary production, extreme difficulty was encountered in making the generator type fuze, due primarily to the vibration associated with the rotating system and to a lesser extent to the vibrations of the bomb itself. The vibration problem remained the most difficult single problem throughout the development and early manufacture of the bomb fuzes. It was found necessary to manufacture certain critical mechanical components to extremely close tolerances and to develop miniature radio tubes which were insensitive to vibration to a degree previously unknown.

Production samples were received from Emerson and Philco in April 1944, and mass production at these plants began in May 1944 and at the General Electric plant in Schenectady in February 1945, and continued until the end of the war. Additional design improvements were made from time to time, until, in June 1945, the quality level was very high and approached the 100 percent ideal. Throughout this period an extensive field test program was carried out at Aberdeen. NBS personnel collaborated with Army personnel in conducting and evaluating the tests.

Preliminary service tests of the bomb fuzes led to minor modifications in the course of production. Chief among these was a device to provide delay in arming (in addition to that built into the fuze) which could be adjusted in the field to permit the fuzes to be dropped safely through deep formations of bombers. It consisted of a small auxiliary vane and gear train externally clipped to the fuze, which released the fuse vane after a pre-selected amount of air travel. The device was designed by J. Rabinow of the Bureau staff and was engineered for production by Globe-Union, Inc. All bomb fuzes were subsequently equipped with this device.

As had been discovered earlier, the "transverse excitation" type of fuze offered certain advantages in air-to-ground bombing. Specifically, these advantages were: (1) good performance from high altitude; (2) less dependence on bomb dimensions; (3) greater sensitivity; i.e., greater burst heights. The necessary circuit research was initiated in April 1943 by a group headed by A. V. Astin, and in August models were made and field tested, and the feasibility of the design was established. In August 1943, the Zenith Radio Corporation was asked by Division 4 NDRC, to undertake the production design of this type of fuze. Production designs were completed in June 1944, and models of the Zenith design were received and tested in July 1944. These first samples gave very good performance. Small-scale production began at Zenith in August 1944, and gradually increased through the remainder of the year. Large-scale manufacture began in January 1945 with the transfer of the production contract to the Signal Corps and continued until the end of the war. A uniform and very high quality level was maintained throughout the entire production period.

A third type of bomb fuze was developed by the Westinghouse Electric and Manufacturing Company (Baltimore and Mansfield plants). This type also utilized the "transverse excitation" antenna scheme, but employed a
different type of generator and driving mechanism and different fuze circuits.

The Generator-Powered Rocket Fuze

After the bomb fuze development had passed into the manufacturing stage, the Navy proposed that the OSRD adapt this type for use on the new Navy 5-inch aircraft rockets. These rockets carry a modified 5-inch shell as the war-head and are about 6 feet long. They can be fired from airplanes with remarkable accuracy using launching equipment so small that it adds very little drag to the airplane. Eight such rockets were mounted under the wings of airplanes, thereby providing them with the equivalent of heavy caliber guns.

Laboratory work and field tests established that the bomb fuze being manufactured by the Philco Corporation could be readily adapted to use on this rocket for either the air-to-air application or air-to-ground use.

Upon completion of the design of the electrical and mechanical modifications, pilot production was begun at Bowen and Company in October 1944, and the design was "proved-in" during the following weeks. In November Philco was asked to initiate production of the air-to-ground version of this fuze; and in December, 1944, General Electric, also manufacturing bomb fuzes, was asked to start production of the air-to-air version.

Development of a new rocket fuze meeting all service requirements was virtually complete in June, 1945. It featured an enclosed turbine drive for the generator and gear train, self-destruction and variable arming time as field options, and a change-over switch for air-to-air or air-to-ground operations. The mechanical design was similar to that for the mortar fuzes, with a considerable reduction in size over previous rocket fuzes.

The Mortar Fuzes

With VT fuzes successfully developed and produced for all common projectiles except trench mortars, and designs having progressed to the point where a VT fuze small enough for the 8-pound mortar projectile appeared possible, Division 4, NDRC, and the National Bureau of Standards were asked to undertake this development. Preliminary design work started in the late spring of 1944, and the project was given top priority by the Army early in 1945. The NBS contract with Division 4, NDRC, was taken over by the Ordnance Department on May 1, 1945, and the mortar fuze development project was carried out henceforth under the joint direction of the Ordnance Department and Division 4, NDRC.

The design of a fuze for 8-pound mortar required the solution of two major problems: ruggedness and size. Whereas the early rocket fuzes were designed to withstand a shock 1,000 times the force of gravity and the bomb fuzes had to stand up under normal rough handling in use, a mortar fuze must withstand a firing shock of 10,000 times the force of gravity. In addition, mortar projectiles are so small that fuzes of the size of those used on bombs would spoil the flight of the projectile and make the round useless. Wind tunnel experiments indicated that if the VT fuze could be held to a diameter of 2 1/8 inches and length of some 3 inches, satisfactory operation could be obtained. This required a reduction of 3 to 1 in volume as compared to bomb and rocket fuzes and yet the fuze was required to perform all the functions of these fuzes.

Early design work followed two general patterns. Globe-Union, Inc., cooperated with the National Bureau of Standards under Division 4, NDRC contracts in a design of a fuze whose general features followed the earlier rocket and bomb fuzes, but whose detailed design represented a marked advance over earlier models. A novel and highly significant feature of this design, carried out by Globe-Union at the request of Division 4, NDRC, was the manufacture of circuit components, such as resistors and condensers and the connections between them, by a new process involving the use of ceramics, thereby obtaining a material saving in space. This is a radical departure in assembly technique and may relegate other methods to the museum.

The second design was prosecuted in its development stages by the University of Florida, using a small loop antenna instead of the projectile body antenna. The circuit
design and power supply followed closely the designs of previous fuses. A small number of models were constructed by the University of Florida and successfully tested. This design was taken over and engineered for production by the Zenith Radio Corporation.

A variation of the first design, developed by the Rudolph Wurlitzer Company in collaboration with NBS engineers, was externally similar to that built by Globe-Union, but differed from it in internal design. Since it was known that both would give good operation, and since no experimental evidence was at hand to demonstrate the superiority of one over the other, it was decided to build both types.

Throughout the development and early production period, field testing was done at the NBS field station at Blossom Point, Maryland, under the direction of R. C. Tobey and at the University of Iowa field station at Clinton, Iowa, under the direction of C. E. Noble.

At the close of the war the Army production program for 100,000 mortar fuses per month was beginning at the Globe-Union Company of Milwaukee and their subsidiary, Rewelec Mfg. Company of Lowell, Mass. Designs were complete at Zenith and Wurlitzer, and procurement was well under way for an additional 300,000 fuses per month from these plants. The close of the war brought abrupt cancellation of all of these contracts which had been initiated against the contingency that the war in the Pacific would last until mid 1948 or early 1947.

Production

From the production viewpoint the radio fuze presented an enormous challenge to production engineers. It is generally called an electronic device, and yet is more complex mechanically than electrically. Designs required a nice balance between the perfection and the producibility of each part. The radio fuze is comparable to a highly sensitive radio instrument electrically, and to a fine time fuze mechanically. Few manufacturers were completely qualified in both fields. To handle its phase of this problem, the Ordnance Development division, in March, 1943, set up a Production Engineering section.

As each fuze design progressed to the point where minimum satisfactory performance was achieved, production was started immediately. Final designs were drawn up and frozen. Orders were placed with component manufacturers, and in many instances new component production facilities were set up. Meanwhile, development was proceeding with the primary objective of improving the fuze performance.

The practice of setting up preliminary or "pilot" lines in the various factories was generally followed. By this means a trial of the production procedures and a test run of the production designs was obtained during the period when procurement for the large production runs was under way.

In addition to the factory pilot lines, Division 4, NDRC, maintained its own pilot lines, which were operated not only through the development period but through the production period as well. Members of the Bureau staff collaborated in administration and direction. Pilot lines were set up at the Zell Corporation, Baltimore, in 1943, and at Bowen and Company, Bethesda, Maryland, in 1944. The latter company was maintained as a facility until the end of the war. The usual production rates were from 80 to 125 fuses per day.

After mass production had started, the problem of keeping quality high became a major effort. NBS personnel spent much time at the plants of the manufacturers assisting with specific problems and helping them avoid difficulties which had arisen in other plants. The manufacturers themselves were very cooperative in sending their engineers to the Bureau and even to the plants of their peace-time competitors for information and advice.

To facilitate this cooperation, early in 1944 the NBS established what later became known as a "Paul Revere Squad." This consisted of a group of field engineers under the direction of Cledo Brunetti. They traveled to the various plants, as needed, to help establish production procedures, introduce new techniques, and offer suggestions in an effort to reduce reject percentages
and increase production. These men were the advance guard for a group of more or less permanent resident engineers who were established at the plants late in the fall of 1944.

Another check on the manufacture of these fuzes was the establishment of the Control Testing laboratory at NBS headed by L. B. Hellprin. This laboratory received a sample of every lot of fuzes manufactured at each of the various plants. Engineers performed numerous tests on the completed fuzes, including temperature, humidity and salt spray tests. In this way a continuous check on all production was obtained and in addition all fuzes were manufactured to a central set of standards, resulting in a uniform product.

The final check on quality of production was always the field performance. Samples from each lot were sent to the field and expended on the proper vehicle in order to see whether or not the fuze functioned properly and to determine the height of function. Statistical studies of these results gave a very good criterion of performance of the over-all design and the score of any particular sample showed whether or not the lot was up to standard.

The production started with pilot contracts under NDRC sponsorship which were shifted to Signal Corps contracts when mass production began.

Tests of Effectiveness

While the superiority of the radio proximity fuze may be surmised from a casual survey of its operation, a scientific evaluation of the potentialities of the fuze can be established only by employing the fuzes in real or simulated combat under systematically controlled conditions and by carefully observing the results.

The first test of the effectiveness of air burst rockets—or, so far as is known, of any air burst weapon—against ground targets was started in February 1943, and completed with full-scale effect field tests in the latter part of 1943 at Fort Bragg, North Carolina. M-8 rockets were equipped with radio fuzes and with superquick contact fuzes. These were fired into an effect field and the results with the two fuzings compared. The effect field consisted of 1 by 6 ft. boards, 1 in. thick, spaced 15 feet apart in a checkerboard array, laid 1 inch below the surface. After each round was fired, the number of boards which were hit at least once by fragments which penetrated a distance of 1/4 in. into the wood, were counted. Twenty rounds with radio proximity fuzes and twenty rounds with superquick contact fuzes were fired over the effect field and scored. Results showed rockets with radio fuzes produced on the average 5.2 times as many casualties as did the contact fuzes rounds. Burst heights averaged 60 feet.

An exhaustive study of the effectiveness of air burst bombs in inflicting casualties against entrenched personnel was carried out by the AAF Proving Ground, Eglin Field, Florida, in the latter part of 1944.

These tests established the fact that a superiority of air burst over contact burst of up to twenty to one is achieved under these conditions. In the same test it was found that if the target is flush with the surface, a factor of superiority of five to one is observed, a result in good agreement with the Fort Bragg tests.

A similar series of tests of effectiveness of airburst bombs against shielded targets was carried out at Ashley Walk, England, also during 1944. A. V. Astin collaborated with British scientists in conducting the tests and evaluating the results.

Another series of tests at Eglin Field led to a new application of VT bomb fuzes—use on the new "gel-gas" fire bomb. These bombs, containing up to 165 gallons of emulsified gasoline, are designed to spread burning gasoline over large areas upon exploding. However, when they are dropped from high or medium altitudes and fuzed to explode on impact, the bombs penetrate the earth for some distance before exploding, and a considerable amount of the incendiary material remains in the crater, reducing the effectiveness of the bomb. This wastage is overcome by fuzing the bombs to explode before impact, so that no crater is formed. Extensive tests of these applications were carried out at Eglin Field and at Edgewood Arsenal, and it was found that for high and
medium altitude bombing, the burned area was doubled when VT fuzes were used.

While much of the foregoing discussion has been devoted to effectiveness of the fragments from a bursting bomb, it must be recognized that there is also a blast associated with bomb bursts and that the importance of the blast increases with increasing bomb size. Damage inflicted by very large bombs is almost entirely due to blast. Investigations by Division 2, NDRC, and by British scientists as well, established that the area of damage to buildings by blast is increased 50 percent to 100 percent by bursting the bomb in the air.

An evaluation of the effectiveness of the air-to-air rocket fuze was carried out at the Naval Ordnance Test Station, Inyokern, California, in early 1945. In the initial phases of the test, high explosive war heads were used on the rockets, and three drones were destroyed with six rounds. Subsequently, in order to avoid further destruction of drones since the primary interest was in the position of the bursts, inert war heads were used, function being indicated by the flash of a small charge of powder. Eight-one rounds were fired at the drone at ranges of 400 to 800 yards, and of these, 58 functioned near the drone, the other rounds passing outside the radius of action of the fuze (about 70 feet). Approximately half of the functioning rounds in this phase of the test were at such distances as to result in almost certain destruction of the drone, if high explosive war heads had been used. It is interesting to note that only one of the 57 rounds actually struck the drone and presumably there would have been but one "kill" if contact fuzes had been used.

**Operational Record**

The VT rocket fuze was developed primarily as a defense against enemy bombers, which were so effective in the early days of the war. As the number of enemy bombing missions decreased, however, and heavy Allied bombardment increased, the urgency of keeping all information on the VT fuze development out of enemy hands became even greater, since such a fuze might well have been used against us with great effectiveness.

All possible precautions were taken in using VT fuzes to insure that none reached enemy hands. Thus, fuzes for use against aircraft were designed for self-destruction some time before striking the ground in case of a miss, while in air-to-ground bombardment, the projectile carried an auxiliary contact fuze which functioned on impact in case of a failure of the VT fuze. However, in using large numbers of fuzes, it is impossible to insure that no rounds will reach the enemy in such condition that he may utilize them.

Accordingly, the Combined Chiefs of Staff decided to limit the use of VT fuzes to operation from warships remote from land until the latter stages of the war when the enemy would no longer have sufficient time to capitalize on possible capture of a sample fuze. The stockpile of rocket fuzes manufactured in 1942 and 1943 constituted a powerful reserve weapon for release in case of a serious enemy threat to Allied air supremacy.

VT fuzes were officially released for general use in December 1944, for the great assaults that were to end the war. Requests for bomb fuzes were received from various theatres of operation and combat use began shortly thereafter.

The first major combat use of VT bomb fuzes was by 7th Air Force bombers operating from Saipan and Guam in the pre-invasion saturation bombardment of Iwo Jima in the period February 10 to 17, 1945. In three missions during this period, 500-lb. and 280-lb. bombs were dropped on antiaircraft installations and beach defenses on Iwo Jima. Antiaircraft fire from the island, previously intense, was reported practically eliminated as a result of these missions.

Subsequently, the fuzes were employed by the 7th Air Force against Marcus Island, Palau Island, the Ryukyu Islands, and the mainland of Japan.

In the Mediterranean Theater of Operations, the 15th Air Force used the VT bomb fuzes on fragmentation bombs against enemy flak positions that defended the avenues of approach into Austria and Germany. The
initial use in Italy was on April 1, 1945, when 15th Air Force bombers flying at 25,000 feet dropped fragmentation bombs against German flak batteries. Each of six batteries attacked ceased firing as the bombs exploded.

VT bomb fuzes were used by the 12th Air Force in Italy in support of the April 1945 offensive of the U. S. Fifth and British Eighth Armies. VT-fuzed general purpose, fragmentation, and "gel gas" bombs were reported to be deadly against personnel and material shielded from ordinary contact bursts by walls, revetments, or foxholes.

During this period, the VT bomb fuzes were employed tactically by the Ninth Air Force, some of the early missions being carried out in mid-March against Flensburg and Neumarken, Germany. As a result of preliminary experience with the fuzes in this theatre, a practice of loading the first three planes in a mission with VT-fuzed fragmentation bombs for use against antiaircraft positions at the target was instituted. The other planes of the mission loaded with standard contact-fuzed bombs for demolition work followed at some distance and approached the target with almost no risk.

Navy carrier-based aircraft began using VT bomb fuzes in the spring of 1945 and employed them in increasing numbers throughout the summer. In the final strikes by the Third Fleet against the Japanese mainland in the period July 10 to August 16, about one-third of all bombs dropped by the carrier planes were VT fuzed. Reports from ships participating in this operation show the following use of VT fuzes during this period (expressed as percentages of total bombs dropped): U.S.S. SHANGRI-LA, 37%; U.S.S. RANDOLPH, 35%; U.S.S. BENNINGTON, 30%; U.S.S. SAN JACINTO, 30%; U.S.S. INDEPENDENCE, 37%. Repeatedly, pilots reported diminution or cessation of antiaircraft fire as a result of air burst bombs.

"In the opinion of the Commander CVEG-50, the 260-lb. fragmentation bomb with VT fuze is an excellent weapon for attacks on revetted positions and is far superior to W.P. bombs and to rockets."

It is noteworthy that in practically every instance reported in which air-burst bombs were used against enemy antiaircraft installations, sensational diminution of fire resulted. The effectiveness of air-burst bombs against such targets is readily understood when it is realized that a contact burst to be effective must actually fall within the revetment surrounding the gun. A contact burst, outside the revetment, even very close to the walls, is ineffective, whereas an air burst fifty or more feet outside the revetment showers numerous high-velocity fragments inside the revetment and makes the position untenable. Thus the number of effective hits against an enemy position with a given bomb load is tremendously increased using air burst. This pays off in fewer casualties among the attacking planes and greater precision in bombing since the chief disturbing factor in precision bombing is eliminated.

An essential phase of the introduction of any new ordnance item into combat use is the instruction of the people who are to use it. This is particularly true of devices as novel as VT fuzes. To carry out the necessary instruction, a training course in the operation and use of VT bomb and rocket fuzes was set up at the NBS and Aberdeen Proving Ground in January 1946.

To provide advance information about the fuzes and instruction in their use, several members of the Bureau Staff were sent by the Office of Field Services, OSRD, and by the Army to England and to the European Continent in the fall and winter of 1944 and early 1945. W. S. Hinman, Jr., followed by A. V. Astin, and later by R. D. Huntcon, contacted units of the 8th and 9th Air Forces and Royal Air Force explaining possibilities, limitations and operation of the fuzes and ascertaining service needs. Captain W. G. Finch and Captain W. C. Bennett of the Ordnance Department introduced the bomb and rocket fuzes into the Mediterranean Theatre. Major S. P. Willan of Aberdeen Proving Ground was sent to the European and Mediterranean Theatres in early 1946 to advise in the use of the bomb and rocket fuzes. F. S. Atchison of the Bureau staff andLt. E. V. B. Stearns of the Ordnance Department accompanied the initial shipment of fuzes to Saipan in January 1946, and provided advance instruction.
THE AIR BURST PROXIMITY FUZE

In the use of the fuzes to the 7th Air Force, leading to initial use of the fuzes on Iwo Jima.

Bomb Director

As the result of a suggestion by Colonel H. S. Morton, Ordnance Department, A. U. S., and Dr. Alexander Ellett, Chief, Division 4, NDRC, the development of a new, long-range bomb sight for dive bombers was undertaken. Successful field tests in the spring of 1944 evoked considerable interest in the Navy Department with the result that the Bureau of Aeronautics and the Bureau of Ordnance requested Division 4, NDRC, to design and procure a quantity of equipments suited to service requirements through the facilities and staff of the Bureau of Standards.

Some fifty persons were employed on this project, and production of the equipment was started about 6 months prior to the war's end. Over 200 of these bomb sights were manufactured by the Bureau for the Navy and Army.

There was limited, but highly successful, use of the equipment in the European Theatre of Operations by the Ninth Air Force, to whom a small number of bomb directors were delivered.
4. Guided Missiles

One of the major war activities of the National Bureau of Standards was the development of guided missiles in cooperation with the National Defense Research Committee, the Bureau of Ordnance, Navy Department, the Massachusetts Institute of Technology, Vidal Research Corporation, Zenith Radio Corp., RCA Mfg. Co. and Bell Telephone Laboratories. This activity began in the fall of 1940 when Dr. R. C. Tolman and Dr. C. C. Lauritzen of Division A of the National Defense Research Committee requested that the NBS permit the appointment of Dr. H. L. Dryden as aerodynamics consultant in connection with a contract with RCA Mfg. Co. for the development of a glide bomb capable of being directed to its target by radio remote control, utilizing television sighting. The aerodynamic characteristics of the missile development by a sub-contractor were found to be unsatisfactory and the NBS was asked to undertake the aerodynamic and servo development for a new design, beginning early in 1942. It was decided to use models with a total weight of about 400 lb., and a contract was made with Vidal Research Corporation for their construction.

In April 1942 the Bureau acquired the use of an area for flight tests near Warren Grove, N. J. where tests were made with aircraft supplied by the Bureau of Aeronautics, Navy Department, and the Naval Aircraft Factory. The gliders developed by the NBS were thus brought to the attention of Naval officers concerned with guided missile development. In July 1942 some of the tests were witnessed by Captain D. P. Tucker and Lt. Commander G. W. J. Dan Junas of the Radar Section of the Research and Development Division of the Bureau of Ordnance, Navy Department, who for some time had been interested in the development of a radar homing missile. They believed that the model itself might be useful as a weapon when equipped with radar homing equipment, for which projects had been established by the Navy at the Naval Research Laboratory and at the Radiation Laboratory of the Massachusetts Institute of Technology. From this period on several developments were prosecuted simultaneously but for clarity each will be discussed separately. Division 5 of the NDRC was organized on Nov. 19, 1942 and the Bureau continued work on guided missiles under its sponsorship. All of the developments utilized a glider which has been developed in 3 sizes and designed to be carried externally on the dropping airplane. The unique type of aerodynamic control used, especially suitable for homing missiles, was developed by W. H. ~ Boyd of the Aerodynamics Section.

Robin Development

The project designated Robin contemplated the development of a missile incorporating a television transmitter with pick-up tube in the nose of the bomb and manual remote radio control by an operator using a television receiver in front of him. The television equipment used in the tests was developed by the RCA Mfg. Co.

The full scale missile was to carry a standard M-34 2000-lb bomb as pay load. Twenty-six model gliders and 14 full-scale gliders were flight tested in connection with this project. Twenty-four of the flights were with television equipment. The principal difficulties encountered were electrical interference, microphonics from the noise and vibration of the glider, and failure of the equipment to remain in adjustment under conditions of varying humidity, temperature, and pressure.

This series of tests includes those made in connection with the development of the glide and servo control. Gyro-stabilization was introduced in the seventh test. In the remaining tests there were 3 failures of stabilization equipment and many failures of recovery devices whose use was felt to be necessary because of the limited amount of equipment available.

The full scale gliders were dropped at Eglin Field, Florida, with the cooperation of the Army Air Forces. The tests were
concluded in July 1945 when there appeared to be little military interest in this missile and a greater interest in radar homing. The television equipment has since been much improved, and experience in the Pelican and Bat developments has shown how to improve the servomechanism. Target identification, and reduction of boresight and pursuit errors remain the major problems. The Robin development was initially carried out by a small group recruited from the NBS Aerodynamics Section working under the direction of H. L. Dryden.

**Pelican Development**

The more important missiles developed were radar homing missiles, i.e., missiles which automatically seek out their target and guide themselves to hit the target.

Radar homing missiles are of several types. If the target is an enemy radar transmitter emitting radio waves, the missile may contain a receiver tuned to the enemy transmitter and home on the transmitter. Other targets must be illuminated by a radio transmitter. The transmitter may be either in the missile, on an airplane, or on the ground. If the missile contains only a receiver and the transmitter is on an airplane the system is termed RHM. If the transmitter as well as the receiver is in the missile, the system is termed SRE. A pulsed radar system is used, the transmitter emitting short pulses or wave trains of high intensity. Directional information is obtained from the returning echoes. It is possible to "tell" the missile which target of a group it is to hit even when the target is one of a large convoy of ships.

The development work on radar homing was carried out by the Radiation Laboratory, Massachusetts Institute of Technology, under the sponsorship of Division 14, NDRC for the Army and Navy and for Division 5, NDRC. The first flight test of a missile with an experimental radar receiver was made at the Bureau's Warren Grove test area on November 12, 1942, against a transmitter on the ground. The first two tests were unsuccessful. Such was the beginning of a long list of over 200 flight tests with receiver only in the missile. As is frequently the case in such developments, attempts to move fast led to difficulty and to retracing of steps with fuller instrumentation. There was much concern with recovery techniques in the early stages when supplies of equipment were limited and much of it had to be reused. Some changes were made in the goals when the military situation and the tests themselves suggested changes to be desirable.

In order to handle adequately the growing program of missile development and to assist the Navy in the assembly of missiles for evaluation and training purposes, the Bureau agreed to interrupt its work in hydraulics and devote the hydraulic laboratory building and its staff to the guided missile program. A special projects section was established in the Division of Mechanics and Sound under experienced NBS staff members who constituted the scientific and technical leadership of the new section, which grew to a membership of more than one hundred persons. The principal groups were (1) engineering development comprising aerodynamics, stabilization, servo-controls, radio and electrical problems, special problems; (2) production engineering, assembly, inspection and testing comprising engineering design, shops, assembly groups, camera group, test group; and (3) field tests comprising theoretical studies, field test group, and field data reduction.

As the priority of the development was increased and early use by the Navy was foreseen, the Bureau requested more formal and direct participation by the Navy in the development and testing. Just prior to the formation of Division 5, NDRC, the Bureau of Ordnance, Navy Department, established both the Bureau of Ordnance Experimental Unit, consisting of officers and enlisted men stationed at the NBS under the command of Lt. Commander G. W. J. Dan Junas, and also the
Pelican Test Group under Lt. Commander L. J. Stone at Lakehurst, N. J. to furnish airplanes for flight tests. Steps were taken by the Navy to place the missile in production, assembly to be made by the National Bureau of Standards. Responsibility for the radar equipment remained with Dr. E. M. Lyman of the Radiation Laboratory, field research and tests at Warren Grove, N. J. being conducted by Dr. P. R. Stout and a NBS field party. The production contract for the radar receiver was placed with the Zenith Radio Corporation, that for the glider with Vidal Research Corporation.

At one time the personnel of the Bureau of Ordnance Experimental Unit stationed at the National Bureau of Standards numbered about 200 officers and enlisted men. The establishment of this unit greatly accelerated the development and created a group within the Navy familiar with the new weapon and therefore able to use it immediately.

The first flight showing homing control was made on December 8, 1942, the target again being a beacon on the ground. Following 3 additional tests of this nature, the first test on an echo from a sphere suspended from a barrage balloon was made on January 7, 1943. The original target, a 5.5 foot sphere, proved somewhat small and was replaced in the next few months successively by a larger sphere and by sections of larger spheres. The weight of the target was limited by the lifting capacity of the available barrage balloons. In flights 10 to 25 inclusive, attempts were made to determine the best adjustments of various parts of the equipment. However, there was evidence of considerable hunting and the magnitude of the error depended greatly on the stage in the hunt cycle at which the target was reached. It was decided to provide additional instrumentation and to introduce stabilizing devices to reduce hunting.

In the ensuing tests various unforeseen difficulties were encountered, both aerodynamic and radar. The discovery of these difficulties and the development of an improved target selector circuit delayed the freezing of a production design.

The first production glider was tested on June 10, 1943, as flight test 43, and the first improved target selector on July 20 as test 50. Flight tests 52 to 56 against an elevated beacon gave substantially improved performance. Several tests in August and September against echoes from an elevated sphere gave excellent results. Camera stations were installed to enable more accurate measurement of the errors.

Attention was then turned to tests against a water target and to illuminating techniques with the transmitter in an airplane, all previous tests having been made with transmitter on the ground. The first tests of this nature were made against a barge in the Chesapeake Bay in October 1943. The results were only fair.

All of the previously described tests were made with missiles weighing about 460 pounds. By this time the originally intended use of the missile appeared less attractive because of the change in the tactical development of the war and at the request of the Navy the glider was redesigned slightly to accommodate a larger pay load. At about the same time the Radiation Laboratory group under Dr. Lyman withdrew from active participation, the major part of the research program having been completed. A production engineering and developmental research group was organized in Division 5, NDRC, as an M.I.T. Field Station located at the NBS. Commander L. P. Tabor assumed command of the Bureau of Ordnance Experimental Unit, and Commander G. E. McCrackin took over the Pelican test group.

The first tests of heavier gliders both against water targets and a ground beacon were unsuccessful. Some twenty flight tests were made from January to May 1944, against an elevated beacon for various experimental purposes. The first test with a Zenith production unit was on February 18th as test 89. A group of 4 tests in April gave reasonably good results. Finally on June 22,
1944 six standard production missiles were dropped against the "James Longstreet," a ship hulk about 437 ft. long with superstructure extending 35 to 40 ft. above the water line at anchor in the Atlantic Ocean about 50 miles from New York City. The results were a complete failure, not a single missile homing on the target. These were the first tests of production missiles. The difficulties were minor in character and easily corrected although this was of course not known at the time.

Some months previously the Navy had decided to organize a few squadrons to use this missile in combat. Production of a limited number of missiles was undertaken by the Bureau of Standards. Shortly after the above failures the Pelican project was returned to a development status. This action was taken largely because of the prospect of the early availability of Bat, whose development had been concurrently in progress.

A series of tests of production missiles at Warren Grove against a ground beacon showed no explanation of the failure against the ship. The results suggested a minor change and indicated that the target selector could not have functioned correctly in the sea tests. Extensive study was made of the problem of keeping the target illuminated with radiation from the radio transmitter. Slight changes were made in the adjustment of the target selector circuits to give improved performance. The next series against the ship were successful.

The last test in connection with the Pelican project was made on October 30, 1944. Pelican receivers have been used against ground beacons as targets for many special tests in connection with the Bat project.

Bat Project

The Bat was the first fully automatic guided missile to be used successfully in combat by any nation. The code name "Bat" suggests the principle on which it operates. Live bats give out a short pulse of sound and guide themselves by the echo, while the Bat missile emits short-wave electrical radiation and is directed by the radar echo from the target. The radar robot pilot can "see" the target under any conditions of visibility, i.e., night, fog, or cloud.

Development of this complex weapon resulted from close cooperation between a number of agencies. Dr. Hugh L. Dryden, of the National Bureau of Standards, coordinated the technical work of the civilian agencies, while Captain Dundas P. Tucker and Commander L. F. Tabor, both of the Bureau of Ordnance, integrated the activities of the military groups. Development of the radar robot pilot was the work of scientists of the Massachusetts Institute of Technology, Cambridge, Massachusetts, headed by Ralph Lamm and Dr. Perry Stout, and of the Bell Telephone Laboratories, where Russell C. Newhouse was in charge. Hunter Boyd and Dr. H. E. Skramstad of the Bureau of Standards, were in charge of the aerodynamic research and stabilization development, respectively. Commander Otho McCrackin, of the Naval Air Material Center, representing the Bureau of Ordnance, supervised flight tests.

The preliminary design of a glider of 10-foot span was started in June 1943 and construction of the first glider in September 1943. This was intended for use with the Pelican receiver. The Navy had placed a contract with Bell Telephone Laboratories for the design of an S3B radar homing system early in 1943. In October these designs were crystallized and in January 1944, one of the first three 10 ft. gliders was sent to Bell Laboratories. The first flight test of a 10 ft. glider with radio remote control was made on May 10, 1944. Seven tests were made with the Pelican receiver during the next few months. As a result of these tests and of wind tunnel tests, the design was slightly modified.

Between October 7 and 10, 1944 a series of 13 tests, 11 with Bat equipment and 2 with Pelican equipment, were made against the ship, "James Longstreet," as target, with excellent results.
According to the official Navy release, this missile destroyed many tons of Japanese combatant and merchant shipping during the last year of the war. Land-based patrol squadrons of Fleet Air Wing One, under command of Rear Admiral John Dale Price, USN, employed the "Bat" effectively against Japanese ships and land targets in the forward Pacific areas.

Two Navy planes, on one occasion, sighted two ships 20 miles away by radar. They went in closer to identify them visually as Japanese destroyers, and were met by heavy anti-aircraft fire. When the PRIVATEERS turned away and got out of range, the Japanese stopped firing. One PRIVATEER then launched its "Bat," which sped through the air, straight for leading destroyer and blew off her bow. The other destroyer rushed to her aid, throwing futile antiaircraft fire in the direction of the mother plane which was outside of range.

Related Developments

During the progress of the principal developments which have been described there were numerous auxiliary studies and tests. The development of the gyro and servomechanism was aided by numerous laboratory tests, by theoretical studies, and by electromechanical models and flight tables. Numerous wind tunnel tests were made by the National Bureau of Standards, the University of Washington, the California Institute of Technology, and the National Advisory Committee for Aeronautics. Tests of components were made at high and low temperatures, under conditions of high humidity, and when subjected to vibration. Strength tests and life tests were made as seemed desirable. In addition numerous special flight tests were made to determine launching behavior, behavior of bombs on impact with water, arming time of fuzes, performance of a destructor system, functioning of live bombs, functioning of folding tail structures, aerodynamic behavior, and effect of modifications of tail size and form.

The NBS also cooperated with the Army Air Forces in tests of certain of their glide bombs at the Warren Grove test area; in return the Army Air Forces furnished the use of certain airplanes for some of the Pelican flight tests. The group also cooperated with the Radio Research Laboratory at Harvard in tests of a system designed to home on enemy radar installations.
5. Radio Propagation, Radio, Radar

The important part played by radio communications during the war brought to light the necessity for having adequate information regarding radio propagation. No matter how good the equipment may be at the transmitting and receiving ends, satisfactory communication is not possible unless the waves are propagated with sufficient strength to be receivable. Variations in propagation conditions may be greater than variations in transmitter power or receiver sensitivity. Furthermore, the extreme crowding of the radio-frequency spectrum makes necessary full utilization of all available frequencies, and the selection of frequencies can be made only with the help of radio propagation data. Also, security considerations dictate that the frequencies used should be the best for the purpose and the least likely to be intercepted by the enemy. The design of equipment, especially of antenna systems, depends critically upon a knowledge of radio-propagation conditions. In addition, other applications of radio, such as radar and direction finding, involve considerations of propagation as regards range and accuracy.

Before the war, relatively few people were engaged in radio propagation work of any sort. At the National Bureau of Standards, radio propagation work began with the low-frequency measurements made by Dr. L. W. Austin in 1909, and extended to the higher ionospheric frequencies (frequencies of waves propagated by means of ionospheric reflections) after the basic discoveries of ionospheric reflections by Breit and Tuve, and Appleton in the decade 1920-1930. In the subsequent decade the NBS extended the scope and amount of its ionospheric measurements, using techniques and equipment destined to be incorporated later in radar, together with studies of the quantitative relations between vertical and oblique incidence ionospheric data, and the variations of radio propagation conditions with time, season, and the sunspot cycle. This work was directed by S. S. Kirby, T. R. Gilliland and Newbern Smith.

The groundwork for the prediction of radio propagation conditions and ranges of useful frequencies was thus laid when, in 1941, the National Defense Research Committee assigned two projects to the National Bureau of Standards: (1) a study of the correlation of direction-finder errors with ionospheric conditions under L. B. Heilbrin, and (2) the preparation of a "radio transmission handbook" to permit usable frequency calculations under Newbern Smith.

In connection with the first project four new ionosphere stations were setup, at Puerto Rico; Baton Rouge, La.; Stanford University, Calif.; and College, Alaska. This increased to 7 the number of ionosphere stations available for use in obtaining a world-wide ionosphere picture; the other 3 were at Washington, D. C.; Huancayo, Peru; and Watheroo, W. Australia, the latter two being operated by the Department of Terrestrial Magnetism, Carnegie Institution of Washington.

In the summer of 1942, the Interservice Radio Propagation Laboratory was set up in the National Bureau of Standards under J. H. Dellingcr and Newbern Smith by the Combined Communications Board of the Combined Chiefs of Staff in Washington, to function along the lines of the British Inter Services Ionosphere Bureau which had existed since early 1941. The duties of the IRPL were to centralize and disseminate all ionospheric and radio propagation data for the U. S., to operate and sponsor operation of such ionosphere stations as were necessary to obtain the data, to cooperate and collaborate with the radio propagation organizations of other countries of the United Nations, to issue radio propagation information and predictions for the use of the armed forces and other cooperating agencies of the United Nations, to train personnel of the armed forces in the use of ionospheric and radio propagation data, and upon request, to make special propagation studies and solve specific problems.

From this time on through the end of the war the scope and activities of the IRPL
continued to expand. They may be considered to lie essentially in two fields: (1) Basic research and development on the ionosphere and on techniques used for radio propagation calculations and predictions. (2) Dissemination of radio propagation information and predictions to the armed forces and associated organizations through regular reports, handbooks, and training courses.

Centralization of Ionospheric Data

The wave propagation group of the Radio Section, first under NDRC sponsorship and later under IRPL, served as a centralizing laboratory for ionospheric data, first for the data from a few ionosphere stations and then for the data from all the Ionosphere stations operated by the United Nations. At the close of the war data captured in Germany and Japan were added to the files of IRPL.

Daily reports of ionosphere characteristics were received from certain of these stations, from various Army and Navy communications centers and from the British Admiralty Delegation to which they had been sent by cable and radio. Monthly summaries of ionospheric data were received by cable and radio through the same sources, and final detailed tabulations were received by air mail. During the war, data received by cable and radio were in cipher form. Coded data also included reports of atmospheric radio noise recorded in a world-wide noise recording program.

A part of data received daily was decoded and retransmitted to various interested parties in the Army, Navy, and FCC. Other parts were used in the determination of ionospheric disturbance ratings for the day and in the compilation of a daily warning. The American Telephone & Telegraph Co. and RCA Communications Inc. contributed to the daily warning service by sending telegrams telling of the start of disturbances. This daily warning was issued to various offices in the Armed Forces.

The received tabulations were used extensively for predicting critical frequencies and maximum usable frequencies in connection with the construction of world charts of predicted ionospheric data. These world charts were predicted four months in advance and issued as a part of the monthly report "High-frequency Radio Transmission Conditions." The first charts appeared April 6, 1942, previous predictions having been in the form of graphs. In September 1944, the title was changed to "Basic Radio Propagation Conditions," this being the first of the IRPL-D series. In some months over 10,000 copies were distributed to the various users.

The basic data from each ionosphere station, from which the predictions were made, were issued beginning July 7, 1943 and finally became the IRPL-F series. The F-series was distributed chiefly to scientific and scientific groups in the armed forces and in civilian life whose activities made it desirable for them to have the basic data.

The predicted maximum usable frequency data were used at IRPL for the prediction of best operating frequencies for practical cases of radio transmission. Data were issued in tabular and in nomographic form for the Armed Forces.

In addition, the predicted basic data were used in the solution of special problems in radio wave propagation presented to the laboratory by the Armed Forces and other agencies doing war work.

A disturbance-forecasting service, first issued as "Weekly Predictions" was begun on October 3, 1942. These disturbance-rating forecasts were for periods beginning 4 to 7 days after the date of issuance.

World-Wide Predictions

The most important achievement in research in the field of sky-wave propagation made by members of the NBS staff was the placing of radio propagation predictions on a world-wide basis. This necessitated the study of the variation of characteristics of data observed at ionosphere stations all over the world and the determination of the effects of location. At first, geographic
latitude was believed to be the chief source of differences between characteristics observed at different locations, but subsequently a well-defined geographic longitude effect was noted. It appeared that the geomagnetic latitude of the station was in many cases the all-important factor and was the cause of the longitude effect. Another important result of these studies was that a good beginning was made toward understanding the manner in which the characteristics of sporadic-E ionization in the ionosphere vary all over the world.

In order to use the data which were being received from all over the world for prediction purposes it was necessary not only to understand their geographic, diurnal, and seasonal variations, but also to determine their relationship to relative sunspot numbers. A simple correlation of values of ionosphere characteristics with relative sunspot numbers had been previously found. During the war, the trends of the variation of these characteristics with sunspot number were determined for the locality of many of the ionosphere stations. A technique of prediction of ionosphere characteristics at any location, using standard statistical methods was developed, involving an estimate of the relative sunspot number for the month of prediction.

A method of representing the latitude variation of ionosphere characteristics with time of day in the form of a world chart for a given month of prediction was developed, and the world was arbitrarily divided into three zones so that longitude effects could be taken care of by the issuing of a chart for each zone for a given month.

By use of continuous field-intensity recordings at oblique incidence and of observations by amateur observers, an ionospheric absorption constant which varied as a function of frequency was evolved and techniques were developed whereby radio distance ranges and lowest useful high frequencies could be determined. World charts of atmospheric radio noise were drawn up in cooperation with the Signal Corps and the techniques modified to include the use of these data where required field intensity was determined by atmospheric noise. The basic equations for the determination of lowest useful high frequency and distance range were put into nomographic form by scientists of the U. S. Navy and finally the atmospheric noise data were put into nomograms of this type at the Bureau, resulting in a very simple method of finding the desired information about radio propagation in any part of the world.

Predictions of maximum usable frequency and lowest useful high frequency were checked by means of analysis of continuous field-intensity recordings and of observed world-wide radio-traffic data obtained from log sheets furnished regularly to NBS by the commercial companies. The effects of sporadic-E ionization in modifying regular-layer predictions were noted. Also anomalies as yet unexplained were observed.

It had been previously noted that radio propagation disturbances could often be correlated with the appearance of sunspots and with geomagnetic disturbances. During the war further investigation disclosed correlation with calcium plages and coronal prominences. During the years of decreasing sunspot numbers it was possible to forecast disturbed periods on the basis of a 27-day recurrence cycle, but with the appearance of the new sunspot cycle this regular pattern of events was broken.

It was further noted that radio propagation disturbances, at least in the Northern Hemisphere, started in the north auroral zone and traveled downward in latitude. It was found possible to determine the advent of a radio disturbance for warning purposes by monitoring stations in Europe whose great-circle paths to Washington pass through the auroral zone. Information on commencement of disturbances was also available from direction-finder observations over these paths, since observed bearings acted differently during a disturbance than otherwise. Other telegraphed ionospheric and cosmic data were also found useful in the determination of disturbances.

An arbitrary disturbance-rating scale of 1–9 was evolved and a technique developed whereby the magnitudes of all phenomena contributing to the forecast of a disturbance
were adjusted to this scale and weighted so that a final disturbance figure could be arrived at for several different zones of the world. A similar technique was evolved for postdate analysis.

Special Services

During the period of the war the wave propagation group and later the IRPL gave consultation and advice to the armed forces and commercial companies doing war work on their special problems involving radio wave propagation. Types of problems included the following:

Best usable frequencies for specified services such as, point-to-point, short-distance tactical operations, phone-to-ground, high-frequency broadcast; ground-and-sky-wave distance ranges under different conditions; types of antennas and lowest required radiated power for a given service; and frequency allocation.

As the techniques promulgated by IRPL began to be disseminated as a result of the training course and the monthly reports, many types of problems, especially those in frequency allocation, were eventually solved by the Army and Navy groups in which they originated.

In the interest of teaching members of the Armed Forces and commercial companies the methods of determining the proper use of radio frequencies, three handbooks were issued and one training course given during the war period.

The first handbook, *Radio Transmission Handbook - Frequencies 1000 to 30,000 kc*, was issued in January 1942. It gave the basic principles of radio sky-wave propagation, and such procedures as were used at that time for calculating skip distances, distance ranges, muf (maximum usable frequencies), and luhf (lowest useful high frequencies). It contained, in addition, world charts of distance ranges and muf predicted for the winter 1941-42, as well as graphs of other basic data, so that problems in frequency usage for that period and, in an approximate manner, for the following winter could be solved. A supplement to this handbook was issued June 1, 1942, which gave summer predictions.

The IRPL compiled the *IRPL Radio Propagation Handbook*, which was issued November 15, 1943. This handbook gave a descriptive discussion of the behavior of the ionosphere and of the theory behind maximum usable frequencies and lowest useful high frequencies. Prediction charts of maximum usable frequencies and absorption constants were given. Techniques for the determination of muf and luhf over any path at any time were given to the extent that they had been developed at the time.

In January 1944 a two-week training course in radio wave propagation was given by IRPL at the Bureau. It was originally intended to be given for 11 picked Army Air Force officers who were to be taught the principles of radio wave propagation and methods of problem solution. Some were then to be assigned to overseas communications groups so that they could put on a scientific basis the assignment of radio operating frequencies in the field. Others were then to be sent to training units within the United States to organize courses in which additional officers could be instructed in this work.

The student body, when the course was finally organized, consisted of 2 groups. In the first group were the 11 AAF officers, 4 officers from the Signal Corps, and 3 Navy officers. The second group attending the IRPL lectures but doing their own problems were 15 enlisted men and one officer from the Radio Propagation Unit of the Signal Corps. A few civilians also attended. A series of 26 lectures was given by scientists and others working directly in radio wave propagation fields both at the NBS and outside. The lectures were interspersed with problem sessions in which the students were coached in the solution of practical radio wave propagation problems.

Field Station Operation

During the period of national defense and during the early years of the war, the NBS
continued routine operation of its pre-war multifrequency ionosphere recording equipment and 12 continuous field-intensity recorders. The station at which this equipment was operated was at Meadows, Maryland until 1942 when it was relocated at Sterling, Virginia.

At Sterling, the routine recording and provisional scaling of ionosphere records and oblique-incidence field-intensity records were continued. An additional multifrequency ionosphere recorder was completed and development of a new panoramic type of ionosphere recorder was started.

In the field-intensity recording program four recorders were added to record field intensities of special transmitters at Beltsville, Maryland, at practically vertical incidence. Work was started on a standard field-intensity recording unit.

Four direction finders of various types were installed, initially in connection with the NDRC direction-error program. In September 1944, personnel shortages compelled the curtailment of observations in this program but one of the direction finders was kept in routine operation in the observation of stations in Europe whose emissions arrived via the North Atlantic path, so as to obtain data for the daily warning service. A program of rural monitoring of stations coming in over the North Atlantic path was also carried on for the warning service.

Microwave Standards

Early in 1944 at the request of the Joint Communications Board an NBS group under Harold Lyons undertook the establishment of national primary standards of microwave radio frequencies. Considerable assistance on this project was received from the Armed Forces, the OSRD, and industrial laboratories. Within a year frequency standards were set up covering the microwave range continuously up to 30,000 Mc/s with an accuracy of one part in 10 million. Fixed frequencies at approximately one-percent intervals were also made available throughout the UHF (300 to 3000 Mc/s) and SHF (3000 to 30,000 Mc/s) bands, with an accuracy better than one part in a hundred million. All frequencies were derived from the group of quartz-crystal oscillators which constitute the national primary standard of frequency. A calibration, test, measurement and information service was established in connection with instruments for accurately measuring microwave frequency.

Progress was made and work is being continued, as requested by the Joint Communications Board, in the development of primary standards and measurement techniques and in providing a calibration service for power, voltage, impedance, attenuation, field intensity, and other electrical quantities at the highest radio frequencies in use. This work may be considered to constitute the beginning of a permanent peace-time program for the development of radio-frequency standards, measurement and instrumentation with the ultimate objective of standards and methods comparable to those available for D.C. and low frequencies.

Radar Countermeasures

During the war a series of radar countermeasures and related projects were assigned to the Radio section (now the Central Radio Propagation laboratory) by the Radio Countermeasures section of the Bureau of Ships, Navy Department.

Project CXFD

This project required the research, design and development of a combination of highly complex electronic circuits to operate under stringent field requirements. While classification precludes description of their specific purpose and operation, some of the problems and difficulties involved are covered in succeeding paragraphs. The requirements set up by the Navy were based partly upon intelligence obtained by the Navy and partly from flight tests of CXFD prototypes against captured Japanese equipment operating at the Chesapeake Bay Annex of the Naval Research Laboratory. Complete laboratory models of the CXFD were
It was necessary to develop special equipment which would make possible quick overall checking of the CXFD and continuous monitoring while in flight on an actual mission. For this purpose the equipment designated as OBY was designed and tested. Twenty-five units were produced on a Navy contract and again production engineering was carried out largely by NBS personnel.

OBY was in reality a miniature radar set consisting of a pulse-modulated transmitter of low power, a superheterodyne receiver of moderate gain, and a cathode-ray oscillograph for visual indication of receiver output. It was weakly coupled to the CXFD antenna through a resistance network.

**Intercept Pulse Repeater**

This project consisted of the development of a long-range intercept receiver and relay that could be operated from a captive barrage balloon about 500 feet above a ship or other installation. This unit would have great range because of the height of the receiving antenna. With such equipment a ship could cruise out of range of the enemy’s search radar without being detected, except for anomalous transmitting conditions, and yet would be able to observe the enemy’s searching activity. The repeater would intercept a radar signal from the enemy’s long-range search radar and relay it to the ship below by means of a very low power transmitter operating at about 250 Mc/s. With this device it would be possible, once the enemy’s frequency was known, to determine if he were searching and if he suspected your presence and position. The equipment was built and successfully tested at NBS; the results and other information were given to the Navy Department.

**Wind Measurement by Radar**

Knowledge of the wind’s velocity in both upper and lower regions of the atmosphere is a prime factor affecting modern naval and air operations. Accurate weather forecasting, which always influences and sometimes determines the planning of air and surface operations, is made possible only through a knowledge of the wind’s velocity.
The first method of measuring wind velocity, widely used for years by meteorological observers, was to send up a pilot balloon and observe its change of position with time, using a theodolite. A method was needed, however, which had greater range and precision and was independent of weather conditions. In 1942 the Bureau of Aeronautics, Navy Department, requested that the Radio Section develop a small, light, inexpensive equipment which would measure wind velocities up to heights of 40,000 feet or more and would use the existing radar facilities installed on shipboard.

Accordingly, development began on a balloon-borne pulse repeater to be used with the Mark IV fire-control radar, which would receive a pulse sent out by a radar and retransmit it back again to the radar. In the usual manner the ship radar measures the distance and direction of the pulse repeater, thus fixing its position in space. The time rate of change of position of the repeater gives its velocity. The chief difficulties in the design of such an apparatus were the limitations set by the specifications of maximum weight, which was 4 pounds, of the temperature range, 40°F to -40°F, over which the apparatus had to be operated (which imposed a problem in frequency stability) and of the power supply.

After considerable experimentation, a satisfactory circuit was developed. The apparatus was powered with two perchloric wet batteries. The total weight of the equipment was 2 3/4 lb. Models of this apparatus were constructed, flight-tested at Chesapeake Bay Annex of the Naval Research Laboratory, and then used as exact pilot models for mass production. Two repeaters operating at 200 Mc/s were developed for use with the radar on board weather and guard ships. One model contained a barometric switch to give altitude indications, by causing the transmission of double pulses at fixed altitude levels.

Parallel with the development of electronic pulse repeaters, a program of development on reflectors for wind-velocity determinations was carried out. A variety of geometric surfaces and antenna arrays were investigated. The most satisfactory type of reflector was the multiple-cube type, which consisted of aluminum foil with pliofilm backing and mounted on a collapsible wooden frame. The reflecting power and maximum range of the reflectors vary of course with the dimensions, number of cubes and the frequency. The reflector is tracked by a fire control or fighter director radar. Wind velocity is obtained in the same way as for the pulse repeaters.

A 12-cube reflector weighing 2 3/4 lb. was designed which could be tracked at 700 Mc/s to 30,000 yards fairly accurately. It was manufactured in quantity. These reflectors were most widely used on weather and airplane guard ships and, to a less extent, on combat ships and at shore stations. Smaller reflectors were also tested for the Navy for short-range work.

The advantages of the reflector over the pulse repeaters consist in their relatively small cost, greater reliability, and simpler technique of operation (no tuning, no batteries to fill). On the other hand, their smaller range (30,000 yards compared to 100,000 to 200,000 yards for a repeater) definitely limits their use to observations of wind velocity at lower altitudes. Also, the signal from a reflector is more difficult to track, with a consequent decrease in accuracy of wind-velocity determination.

Wind Velocity Determination by Phase-Variation Method

The need for a method of measuring wind velocity which would not be limited by conditions of visibility had long been recognized. Such a method, making use of radio signals to and from a free balloon, was demonstrated as a result of work by F. W. Dunmore and L. G. Lapham at the NBS in 1933. The equipment included a transmitter on the ground (modulated by a single audio frequency), a radio receiver, and a free balloon carrying a small transmitter-receiver (remitter) which received the radio signal from the ground transmitter and rebroadcast it on a different frequency to the ground station receiver. The phase of the audio output from
the receiver was compared with the audio modulation of the transmitter. Because of the time required for the signal to travel from the transmitter to the balloon and back to the receiver, any change in the distance between the balloon and the ground station results in a change in phase between these two audio voltages. The original demonstration in 1938 made use of one of the WWI standard frequency transmitters, a commercial radio-communications receiver and a cathode-ray oscilloscope as ground station equipment. The re-emitter was constructed by members of the Bureau staff. The experiment was for the purpose of demonstrating the feasibility of measuring the change in distance to a free balloon by the phase variation method. No provisions for azimuth or zenith angle measurements were made at this time. Later flight tests conducted during March and April of 1938 conclusively demonstrated the phase variation method to be a practical way of measuring change in distance.

In 1941, at the request of the Navy, E. F. Florman and W. C. Pineo of the NBS undertook the development of a complete wind-sounding equipment employing the above described method of distance measurement. The project was completed in 1943.

The receiving equipment included a sharply directive rotatable antenna array with suitable electronic and mechanical controls to cause the antenna to automatically track the balloon, and a manually operated goniometer for adjusting the phase of the 10,000 cps reference voltage to that received from the re-emitter.

The re-emitter consisted of a radio receiver tuned to the frequency of the ground station transmitter and a 73.5 Mc/s Hartley oscillator coupled to a half-wave transmitting antenna. The 10,000 cps output from the receiver section was used to amplitude modulate the 73.5 Mc oscillator. This 73.5 Mc oscillator was also modulated by a relaxation oscillator whose frequency was determined by a barometric switch. Thus the output from the re-emitter after being received and rectified at the ground station receiver consisted of a 10,000 cps signal whose phase with respect to that of the 10,000 cps reference voltage at the transmitter indicated the distance to the re-emitter, and a sequence of tones which indicated the atmospheric pressure at the re-emitter.

The recorder consisted of two raised helix coaxial drums with a printer bar assembly and two cam operated printers. The two coaxial drums were respectively linked by selvin motors and generators to the antenna array and to the rotor of the manually operated goniometer. Thus both distance and azimuthal angle to the balloon were simultaneously recorded on a paper which passed between the drums and printer bar at a constant rate. When a "pressure" tone was heard in the head phones the operator threw one of three switches which would activate the appropriate cam-operated printer and its rate of printing. The pressure record could be converted to balloon altitude. The record thus obtained could therefore be scaled for distance and azimuth angle to the balloon and altitude of the balloon and this data used to plot the horizontal projection of the balloon path on a standard Aerological plotting board.

After approximately fifty test flights were made at the Beltsville, Md., Agricultural research center of the U. S. Dept. of Agriculture the equipment was taken to the U. S. Naval Air Station, Alameda, Calif., where it was operated on a routine basis of one or two flights daily for more than a year. At the Alameda location the azimuth angle to the balloon could be measured to an apparent accuracy of ±1.5 degrees and the distance to the balloon could be measured to within ±50 meters with a probable accuracy of ±1 percent for balloon altitude measurements.

The results of numerous flight tests at Beltsville, Md., and Alameda, Calif., showed that balloon altitudes of from 40,000 to 80,000 feet were consistently attained and that the balloon could be tracked to a distance of approximately 90 miles. Wind velocities exceeding 100 miles per hour were measured at Beltsville.
High-Frequency Direction Finder

From April 1941 to July 1942, a study of high-frequency direction finders was carried out at the NBS under Harry Diamond with N.D. R.C. sponsorship. The frequency range was 2 to 30 Mc/s, emphasis being placed on the problems of direction finding on ionospheric radio waves. It was found that polarization and site errors constituted the largest errors in existing direction finders. The program therefore was chiefly devoted to a study of these errors.

For the study of polarization errors a method was developed having advantages over previously-used methods and applicable to many d-f (direction-finding) antenna systems. In this method a figure-of-merit of the d-f, designated as the "pickup ratio," was introduced. The pickup ratio is the ratio of the pickup factor, $k$, of the direction-finder antenna system for desired radiation field components to its pickup factor, $k$, for undesired field components. The pickup factor here means the proportionality constant that related output voltage per unit field intensity of a particular field component with a function depending on the particular antenna system used and the azimuthal and elevation angles of the downcoming wave. A knowledge of the pickup ratio together with the directional pattern of response of the d-f is sufficient to give the output voltages of the antenna system for fields of complex polarization including that of downcoming sky waves, and therefore makes possible the determination of the polarization errors for such sky waves. Since it is possible to measure the pickup ratio for a wave at horizontal incidence all measurements may be made near the ground. This is a principal advantage of the method; other advantages are that the method yields the maximum polarization error and a figure-of-merit for polarization error which is independent of the ground constants and of the height of the d-f above the ground.

After developing the technique of determining polarization errors through measurement of pickup ratios, a program of measurements was carried out on the following direction finders: (1) an experimental, balanced $H$-antenna of the rotatable Adcock type, (2) a Navy Df, rotatable balanced $H$-antenna, (3) a U. S. Signal Corps Type SCR-551, (4) the Western Electric fixed, crossed $H$-antenna system developed for the CAA and installed at LaGuardia Airport, (5) the Collins Radio Co. model CXAL spaced coaxial loop-antenna system, (6) a United Airlines spaced loop-antenna system with horizontal loop-antennas.

The results on these D-F systems showed much lower polarization errors for those systems using loop-antenna elements than those using open-antenna elements. It was concluded that loop antennas were inherently easier to shield and balance so as to reduce polarization errors than open antennas. The spaced horizontal loop-antenna d-f was found to have the smallest errors of those d-f's investigated and had in addition a low susceptibility to site errors caused by local reradiation, because of the rapid attenuation near the ground of horizontally polarized waves reradiated by surrounding objects.

A theoretical study was made of the state of polarization of downcoming waves. These waves are elliptically polarized having electric components polarized parallel and perpendicular to the plane of incidence independently of the state of polarization of the wave originally incident on the ionosphere. This incident wave is split into ordinary and extraordinary waves which on returning to the earth combine vectorially to give the total downcoming wave. Equations for the fading of these ordinary and extraordinary wave components were derived and expressions found for the variations in the state of polarization of the downcoming wave. The effect of fading was calculated by means of the distribution law first derived by Rayleigh and verified for ionospheric waves by K. A. Norton. It was shown that the state of polarization, in general, varies in a random manner so that the average of a series of swinging d-f bearings will usually give a bearing close to the true bearing, provided
The swinging is caused by polarization error.

A study of d-f sites was made in which it was shown that direction finders designed to respond to horizontal electric field components should have smaller site errors caused by reradiation than a D-F designed to respond to vertical components.

Equations were derived for the field intensity at any given depth below ground for incident, downcoming waves, and an approximate table prepared showing the recommended depth to which cables and lines should be buried in order to avoid reradiation difficulties.

A new method was evolved for rapidly measuring the ground constants of a proposed site, at various points of the site, both to determine its electrical homogeneity and its conductivity and dielectric constant. This method was widely applied by the Naval Research Laboratory in measurements of ground constants for d-f work.
6. Quartz Crystals

Millions of quartz crystal oscillator plates were required by the armed services during the war for use in radio communication. All tanks, planes, and other mobile equipment carried sets of these plates in both transmitting and receiving sets. The plates served to tune both transmitters and receivers to a desired frequency, and permitted quick change from one frequency to another merely by changing crystals which were usually mounted in holders that could be instantly inserted and removed from the circuit. These plates also served to hold the frequency of the carrier wave of a radio transmitting set within very narrow limits and thus greatly increased the number of radio channels available for communication. The procurement of quartz suitable for use in manufacturing these oscillators soon became a matter of grave concern. Quartz crystals of the desired size and quality are not found in significant amounts in the United States. Brazil was practically the sole source of supply.

In March 1940, the National Bureau of Standards was asked by the Procurement Division of the Treasury Department to assist in formulating specifications for the purchase of quartz crystals of radio grade. It was planned to provide a stockpile of at least 100,000 pounds of usable quartz, which was to be drawn upon only at a time of great emergency. The NBS was also asked to undertake the testing of the quartz purchased for stockpiling and this responsibility was accepted by the Polarimetry section under the supervision of Frederick Bates. Procurement of the material was very slow, owing in part to the fact that before the war the United States had purchased only about 4 percent of the quartz mined in Brazil. In 1938 and 1939, Great Britain, Germany, and Japan had secured 94 percent of Brazil's greatly expanded output of quartz.

In April 1940, the first shipment of quartz arrived and was tested. From this time on shipments continued to arrive with increasing frequency, and by December 1940, the project had to be moved into larger and more appropriate quarters. The total amount received, inspected and graded during the first seven months of 1941 was about 45,000 pounds. It soon became evident that American importers, through whom the Procurement Division was obtaining its quartz, would be unable to supply the required stockpile. Accordingly the Metals Reserve Company took over procurement direct from Brazil and a shipment of 100,000 pounds was received in August 1941. Much of this material was, however, of very poor quality, even though many of the boxes carried the stencilled designation "Yokohama."

At the end of 1941 four inspection tanks were in use and the staff had been increased to ten. The output for January 1942, was 34,000 pounds. In February the work was expanded to a two-shift basis. In July 1942, the project was extensively reorganized and enlarged to operate in three shifts. The development of testing equipment and testing procedure was carried out by F. B. Phelps. The volume of production, as well as the elaborate reports required (over one hundred categories of tested materials were required) made necessary the services of a full-time production manager, and W. A. Roche was placed in charge of testing operations. The staff was enlarged to 63 inspectors and 13 laborers, many of whom had to be trained in a special school for their new duties.

Meantime production quotas were steadily being increased and larger quarters became imperative. The Metals Reserve Company, which was financing the cost of the quartz inspection and grading, provided a new laboratory for this purpose, as well as extensive storage facilities. Operations were transferred to the new building in December, 1942, and the staff was increased to 166.

Quartz Research

Prior to the war, it was believed that it was necessary to use untwinned quartz, free from all visible foreign inclusions, in the manufacture of radio oscillators. In other words, optical perfection was used as a criterion of electrical performance. Since the
supply of such material was adequate at the
time, the possibility of using material that
did not meet the above standards had not been
investigated. After large quantities of rock
crystal had been imported and inspected, it
was seen that a very small percentage of it
was free of these defects, and that it would
probably be impossible to obtain enough to
supply the anticipated demand for oscillators.
It became obvious that studies should be
made to determine whether certain defects
could be tolerated in quartz to be used for
oscillator manufacture. Accordingly, a quartz
research laboratory was established, with the
approval and support of the Metals Reserve
Company, in order to determine the extent to
which optical imperfections of various types
interfere with the performance of the fin-
ished oscillator. F. P. Phelps undertook the
task of supervising a separate research lab-
atory which took the form of a small pilot
plant for the fabrication of experimental
quartz oscillator plates. This plant had the
necessary high-grade electrical equipment for
measuring the operational characteristics of
finished plates.

An X-ray unit was purchased, because X-ray
reflection provides the most accurate means
for determining the orientation of the prin-
cipal axes of a quartz crystal. The plates
from which the oscillators are made must be
sliced from the mother crystal in such a di-
rection that their surfaces make specified
angles with the principal axes and these an-
gles must be held within very close limits
in order to secure the best oscillator per-
formance. An improved goniometer for orient-
ing the crystals on the X-ray apparatus was
constructed at the NBS, and modifications in
the ionization chamber and associated cir-
cuits resulted in a considerable increase in
the accuracy attainable in the X-ray reflec-
tion measurements.

One of the first investigations carried
out had to do with the precision of X-ray
measurements. Although an error of 15 min-
utes or less in the X-ray measurement of
crystallographic orientation of the finished
plate was claimed by the manufacturers, yet
the actual error in delivered plates was of-
ten found to be 30 minutes or more. It was
believed that the individual X-ray goniome-
ters were not always in correct adjustment.
The need for some means of standardization
was evident. The research laboratory under-
took the preparation and standardization of
test plates for checking the accuracy of X-
ray goniometers. These consisted of quartz
plates accurately finished to the desired
angles with a precision of ±1 minute of arc.
Both BT and AT standards were prepared and
distributed to manufacturers of oscillators,
together with directions for their use.

By June 1943 the laboratory was in a po-

tion to manufacture quartz oscillators ac-
curately to any reasonable specifications as
to size, thickness, or crystallographic orien-
tation. Systematic checks were being made
on the grading procedure by withdrawing graded
crystals, manufacturing them into oscilla-
tors, and determining directly the percent-
age of usable quartz. The effect of impe-
erfections of various types on the performance
of oscillators was investigated in detail.
Changes in the frequency of a finished os-
cillator with time (aging) were studied in
relation to the final finishing operation
(polishing or etching). The testing labora-
tory played an important part in these in-
vestigations by the discovery and descrip-
tion of new defects, the collection of sam-
ples of defective quartz, and the determina-
tion of the possible effects on the stock-
pile of changes in the specification. The
specification in use at the time the research
laboratory was established was based on the
observations of the testing laboratory cou-
pled with the experience of the production
cutting-shops. Subsequent changes were based
on a coordination of the expanded knowledge

gained in all three activities. Many of the
inquiries of the NBS quartz testing and
research laboratories were carried out in
cooperation with the U. S. Signal Corps, War
Production Board, Foreign Economic Adminis-
tration, and several manufacturers.

Defects in Quartz Crystals

X-ray studies have shown that the silicon
and oxygen atoms in a quartz crystal are ar-
ranged spatially in the form of a spiral.
QUARTZ CRYSTALS

This spiral structure has the effect of rotating the plane of polarization of a beam of light to the right or to the left as it passes through the crystal. A right-hand or a left-hand spiral arrangement is equally probable, and thus we have right-handed and left-handed quartz. Either form may be used in making oscillator plates.

Unfortunately many quartz crystals are "optically twinned," that is, they contain both right-handed and left-handed quartz. Only that which is either all right-handed or all left-handed can be used in making oscillators. This optical twinning greatly reduces the yield of oscillator plates from many large crystals which on casual inspection appear to be of high quality.

In addition to optical twinning, quartz may also be defective owing to the presence of electrical twinning. A bar correctly cut from a normal crystal and subjected to pressure will become positively charged at one end and negatively charged at the other. However, a bar from an electrically-twinned crystal treated in the same manner will become electrically polarized in such a way that both ends will be positive or negative. This subtle non-homogeneity in the crystal cannot be detected by direct optical means. Plates cut from such material will be cut in the wrong orientation throughout a good portion of their length, and will not give the desired frequency, or will fail to respond at all. Fortunately these regions of reversed polarity are usually quite extensive, so that the crystal may be divided into several portions which are electrically true in themselves. This division takes place during the manufacturing process, when each cut is etched with hydrofluoric acid. Etching reveals the boundaries at which the polarity is reversed. Any plate cut so as to include the boundary must be discarded.

Other defects result from inclusions of chemically foreign material in the mother crystal. These defects are detected and their size estimated in the intense, sharply focused, beam of a carbon arc lamp trained on the crystal while it is immersed in oil.

These inclusions may adversely affect the performance of a finished oscillator in which they occur, by altering its electromechanical properties to the extent that the crystal vibrates at an undesired frequency, fractures during acceptance tests, or fails to show any response to the impressed alternating current.

Many of these defects are distributed throughout the crystal in an orderly fashion that corresponds with the crystalline structure of quartz. One sample of this is the phenomenon of "phantom" crystals. These appear as if several crystals of various sizes but of the same orientation had grown within the mother crystal. Actually they mark stages in the interrupted growth of the crystal and the phantom faces were once external faces that became weathered and stained with foreign matter during a period when conditions were not favorable to crystal growth.

Another example is that in which "blue needles" occur in pairs apparently originating from a tiny bubble, to form a V, whose apex points to the base of the crystal and in which each needle is perpendicular to a different rhombohedral face.

Many inclusions have a needle-like appearance and are referred to under the general term of "needles." These range in size from gross inclusions having a diameter and length comparable to a lead pencil (some tourmaline needles), to tiny pale blue needles which can be seen only under specific conditions of illumination, and then only with difficulty. The larger needles have been found to be either tourmaline or rutile. The inclusion of either of these minerals in a piece of quartz completely blocks the piezoelectric effect, making it unusable as an oscillator.

The nature of the much smaller "blue needles" has not been definitely determined. The color ranges from white to pale blue and is supposed to arise from the scattering of the carbon arc beam. In shape they range from thin sharp needles, to flattened "feathers," to shortened "flocules." No one has ever been able to isolate a blue needle from the
mother crystal. When quartz is cut so that the included blue needles are cross sectioned, the resulting plates contain tiny holes, some of which can be detected only with the microscope. All the evidence points to the conclusion that blue needles are formed by entrapped gases or liquids that escape when the crystal is cut. Quartz containing this defect can be used for all electronic applications which do not require high to ultra high frequencies. Quartz containing a large number of bubbles per unit volume appears milky white. Small scattered bubbles have about the same effect on the usability of quartz as blue needles.

Crystals which show the Tyndall effect may appear perfectly clear in diffuse light. However, when an intense narrow beam of light is passed through them, the path of the beam is easily visible and sharply defined, like the path of a beam of sunlight through dust-laden air in a darkened room. The inclusions in quartz that cause this effect are of microscopic to submicroscopic dimensions. Their influence on an oscillator is similar to that of "blue needles."

The carbon arc beam also reveals a defect known as "incipient fractures." Crystals with this defect appear to have a grainy structure comparable to the appearance of weathered ice. Such crystals are rejected.

Other relatively large defects, sometimes appearing as scales or moss-like aggregates, have been analyzed and found to be oxides and sulfides of iron or magnesium-aluminum silicates. Material containing such defects is not suitable for use in making oscillators.

Inspection Technique

To inspect a piece of quartz accurately, it must be immersed in a liquid. The liquid prevents reflections of the inspection light from the crystal surfaces, thus allowing one to look into the crystal. The liquid should have a refractive index as near as possible to that of quartz (1.5441 for the ordinary ray). At the outset, o-tricresyl phosphate was used, which is an odorless, water-white liquid having a refractive index of 1.544 and a low vapor pressure. When this became unavailable early in 1945, a light mineral oil of the "upper lube" type was used. Special equipment was installed to dry and filter the oil to keep it clear. At the peak of production about 600 gallons of oil were processed each day.

For the detection and estimation of inclusions, the crystal is manipulated in a beam of white light from a carbon arc lamp, projected into the oil bath through a glass window in the side of the tank. For the detection and estimation of optical twinning, plane polarized light is used. The light source is a mercury vapor lamp located under the oil bath. This light passes up through a translucent glass diffuser to get even distribution of light over the field, then through the polarizer, a sheet of polaroid which permits only plane-polarized light to pass. From here the light passes through a window in the bottom of the tank, through the oil and through another sheet of polaroid, the "analyzer," supported horizontally above the tank. When the analyzer and polarizer are crossed no light passes, but if a crystal of quartz is now placed between these polaroids with its optic axis parallel to the beam of light, the vibrational plane of the polarized light is rotated in passing through the crystal, and black bands appear. By rotating the analyzer to the right and observing whether the bands expand or contract, the hand of the piece of quartz may be determined. Optical twinning causes a distortion in the interference figure resulting from right and left-hand rotation.

Early in 1943 little raw quartz was being delivered to the NBS from Brazil, and that small amount was being flown in by the Air Transport Command. Because of the German submarine menace, boat shipments had been drastically curtailed. By this time the Bureau stockpile of below-grade quartz was quite high. Some of these rejected crystals contained usable portions, associated with a large volume of defective material. It was believed that by trimming the below-grade portion from the larger crystals, a good yield of usable quartz could be obtained.
A practical trimming technique had to be developed. It was learned that although there is never any cleavage in quartz, the crystal does part more or less parallel to certain planes or crystal directions, when properly struck with a hammer, and this was utilized in the trimming operations. Special trimming tables were designed equipped with large transparent curved shields to protect the operator from flying fragments. As the trimmers became more experienced, it was decided to use the oil-immersion tank as a guide in the trimming, in order to bring the crystals to the highest possible grade. This procedure of trimming, inspecting in the tank, then retrimming was followed in all subsequent operations.

In 22 months of operation, 677,000 pounds of rejected quartz was trimmed and 166,000 pounds of usable quartz was recovered for reinspection.

Most of the quartz crystals from Brazil were small, averaging less than a pound in weight. Some fine large crystals were received, the largest weighing 280 pounds. Crystals weighing less than half a pound were not popular with the manufacturers of oscillators, because the waste in cutting them was relatively much higher than for larger crystals.

Few of the crystals supplied were optically perfect throughout. Most of them had imperfections of some kind, more or less localized. It was the task of the inspectors to estimate the percentage of usable quartz in each individual crystal. To this end a familiarity with the various optical defects already described, and their effect on the performance of a finished oscillator, was necessary. The work of the research group on the performance of oscillators containing various optical defects was most helpful in this connection. The percentage of usable quartz in a crystal, together with its size, provided a basis for grouping the individual crystals into specified grades. Manufacturers purchased these various grades at prices that were roughly proportional to the yield of oscillator plates per pound of material; but the best grades were always in greatest demand.

Space does not permit more than passing mention of the numerous changes that were made in the specifications that governed the grading and classification of quartz crystals. These specifications were established by the war agencies concerned with the purchase and utilization of the quartz, with the technical assistance of the NBS group charged with the responsibility for carrying out the grading. To the quartz testing staff, working under pressure to supply the required amounts of graded material, changes in the specifications always meant an upset in established routine and a temporary slowing in production during the time it took the grading personnel to become familiar with the new schedules. A measure of the additional work necessitated by these changes is to be found in the fact that during the war years more than 2,600,000 pounds of quartz was regraded as a result of changes in the specifications. The progressive changes in the specifications were, however, a definite help to manufacturers in securing material of desired quality and eventually simplified the grading operations at the NBS by reducing the number of grades and classes.

The accompanying table on the following page shows the monthly production figures for the years 1942 to 1945, inclusive. The total amount of quartz tested is greater than the total amount received, owing to the large amount of reinspection made necessary by changes in specifications and the trimming operation.

In addition to the work involved in the grading operations, accurate records had to be kept of each incoming shipment and the yield of usable quartz obtained from it. The graded quartz had to be reboxed and stored and an exact inventory maintained for the stockpile. Detailed records of all shipments and the authority therefor had to be maintained.

The availability of a quartz stockpile of known quality, fairly priced, encouraged new firms to undertake the manufacture of oscillators. In the last six months of 1944, 12 plants manufactured 88,000 oscillators, while in the corresponding months of 1945, 111 plants produced 10,800,000 oscillators.
PRODUCTION OF TESTED QUARTZ CRYSTAL

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<td>35,600</td>
<td>328.100</td>
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<td>65,400</td>
<td>616.000</td>
<td>331.100</td>
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<td>86,600</td>
<td>415.000</td>
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<td>315.400</td>
<td>437.200</td>
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<td>November</td>
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<td>175.200</td>
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<tr>
<td>December</td>
<td>269.200</td>
<td>262.500</td>
<td>126.300</td>
<td>57.700</td>
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Total per Year: 1,616,900
Grand total: 1,183,300

The above production included the following types of material:

1. Original inspection of regular MRC purchases: 5,198,800
2. Reinspection of material graded by National Bureau of Standards: 2,658,800
3. Trimming (and reinspection) of material graded by National Bureau of Standards: 669,300
4. Reinspection of material graded by Signal Corps, Bethlehem Field Station: 902,700
5. Inspection of private importers quartz that was not purchased by Metals Reserve Company: 620,700

Total: 10,050,300

During the latter period, practically all quartz imports by the Government and by private dealers passed through the NBS quartz grading laboratory.

The inspection data enabled interested agencies to prevent the wastage of quartz by inefficient plants. By checking on the quality of material such plants were using and comparing their output of oscillators with that of an efficiently-run plant using the same material, the agencies had a basis for suggesting and enforcing corrective measures. These records also served as a means of evaluating the work of the Government purchasing agents, as measured by the quality of material purchased.

The quartz laboratory also examined and graded samples of quartz obtained in the worldwide exploratory work for this mineral. Over 200 shipments were tested from twenty-five states and Alaska, as well as seventy-three shipments from sixteen foreign countries, but mainly from Mexico, Guatemala, and Colombia. None of these sources produced significant amounts of quartz. Brazil remains practically the sole source of supply.

Piezo-Electric Crystals

Assistance was given the Naval Research Laboratory in growing large crystals of primary ammonium phosphate for use as piezo-electric oscillators. These crystals are grown from a solution containing a mixture of primary and secondary ammonium phosphates. Standard analytical procedures were developed for the determination of phosphate and ammonia in these solutions. As a basis for more rapid routine methods of analyzing the solutions, studies were made of the variation of a number of physical properties of the solutions with respect to their composition. The refractive index was found to change with the total concentration of phosphate and to be insensitive to a change in the ratio of the two salts. The relative acidity in turn was found to be only slightly affected by small changes in the concentration of the phosphate but was sensitive to changes in the ratio of the salts. To make the measurement of acidity sufficiently accurate for the purpose of determining the ratio of the salts, a special electrometric assembly was designed which made use of hydrogen and calomel electrodes instead of the glass or quinhydrone electrodes more commonly used.

During the developmental stage of this project, a spectrophotometric method was devised for detecting the presence of microscopic crystals when the salt solution reached saturation as it was slowly cooled. These crystals had to be avoided in order to get the growth of the large crystals started from single nuclei.
Basic research and development at the NBS in the field of electricity under E. C. Crittenden was necessarily diverted to major war projects. In particular, much effort was put into the proximity fuse and guided missile programs as well as the field of radio propagation.

Fundamental investigations in resistance, capacitance, inductance, and magnetic measurements were curtailed while the growth of war industries taxed the calibration services of the Electricity division. Thus further research, except for a continuation of measurements of the solubility of cadmium sulphate in deuterium oxide as a part of the development of the best possible standard of electromotive force, was suspended. The NBS standard of electromotive force consists of a group of chosen cells of the Weston normal types. Both neutral and acid cells are employed. Other variations in the type, however, are possible, and these were the subject of investigation shortly before the outbreak of hostilities. In making the standard available to war industries, power companies, and to other laboratories, the NBS certified 1,200 standard cells between December 7, 1941, and September 2, 1945, as well as several hundred for use within the Bureau itself.

Excluding the proximity fuse, guided missile, and radio propagation programs, the principal projects of an electrical nature included lightning studies, static electricity investigations, a large program in battery research, the ballistics of guns, counter measures against magnetic mines, considerable electrical instrumentation, various calibration services, and the development of specifications for the purchase of electrical supplies by the armed services and the Government in general.

Lightning Hazards to Aircraft

In the early stages of the war, the shortage of aluminum led to the growing use of plywood structures for airplanes, such as the British "Mosquito" bomber, and for gliders. To tow a wooden glider through the thunderstorm ridden areas of the Southwest Pacific with a plywood airplane would obviously be almost suicidal because the non-conducting wood could not offer protection to the crew inside. Yet the ability to transport troops and supplies over relatively long distances in this way and hence without adequate information of meteorological conditions near the destination might be a determining factor in a campaign. There was an obvious need to estimate the hazards involved as quantitatively as possible and to find how much protection could be obtained by applying lightning conductors to aircraft without involving excessive weight and drag.

The N.A.C.A. Committee on Lightning hazards to Aircraft, recognizing the importance of this situation, asked the National Bureau of Standards to initiate a theoretical and experimental study of the problem in 1942. The work was directed by F. B. Silsbee and F. M. Defendorf. Funds were transferred from the Bureau of Aeronautics, Navy Department, in partial support of this investigation.

Computations, confirmed by experiments with surge currents up to 50,000 amperes, showed that reasonably light conducting strips of rolled or sprayed aluminum or cooper could be used as effective lightning conductors. These main conductors could be supplemented by strips or areas of conducting paint.

A second type of study involved the measurement of the transient currents flowing in circuits which simulated those between the limbs of a pilot or passenger when heavy surge currents, simulating lightning currents, were passed through the aircraft by various routes such as nose to tail or wing-tip to tail. For this purpose two experimental gliders and a PT-19-A training plane, were furnished by the Army Air Forces.

To interpret such electrical data in terms of the physiological effect on the pilot, it is necessary to know the effect on the human nervous system of electric shocks of very short duration. The meager data on this
point available in the literature were supplemented by measurements of the intensity and duration of surge currents required to produce noticeable shocks in various members of the laboratory staff; and also, with the collaboration of Dr. G. E. Ogden of the National Institute of Health, by observations of the effects of larger currents on anesthetized guinea pigs.

The results indicated that the electrocution hazard, which is very great in an unprotected non-metallic aircraft, could be largely eliminated by the application of a moderate number of suitably placed metal strips combined with adequate bonding of all control cables and other metal parts. General principles were formulated on which the layout of a protective system for any particular aircraft could be based.

Another phase of this problem related to glider tow lines. If there is to be telephonic communication between tow plane and glider, as was at first anticipated, there must be two separate metallic connections between the aircraft. On the other hand if the usual nylon tow rope is used the tow crafts are in effect insulated as long as the nylon is dry. The former condition would obviously greatly increase the probability that the presence of the tow between thunder clouds would trigger off a lightning discharge which would pass through the craft. It was found, however, that the moisture which might accumulate on a nylon tow rope when flying through a cloud would produce enough conductivity to serve as a trigger anyway. Furthermore even if no true lightning stroke occurred, there was sure to be so much corona discharge (St. Elmo's fire) develop when flying near a thunder cloud that the resulting electric heating of the rope could cause it to burn in two or melt.

The remedy developed was to impregnate the nylon rope with sufficient carbon in the form of "aquadag" to keep its resistance so low that the corona current did not produce serious heating. The development of the war in the Pacific largely by water borne forces and the absence of thunder storms near the English Channel led to the decision by the Armed Services that under existing conditions the additional manufacturing process needed to apply the aquadag to nylon tow rope would not be justified.

It should be noted that many of the results of this work will be of value in civil aviation where non-metallic control surfaces are often used.

Static Electricity Hazards

The sparks which result from the accumulation of static electricity in various manufacturing processes, constitute a very material fire hazard in those industries in which explosive vapors and flammable or explosive dusts are present. The NBS was frequently asked for advice on the mitigation of such hazards. The tremendous wartime increase in the volume of such materials handled in the manufacture of explosives, synthetic rubber, and other chemicals and the number of previously inexperienced firms in this field, greatly increased the demand for such information. A circular (C438 "Static Electricity") was prepared, and issued in August 1942, which outlines an engineering approach to the problem, summarizes methods for mitigating this hazard, and gives references to other useful sources of information.

The Army Engineers were much concerned with the possibility that static discharges might ignite the anesthetic gases used in the operating rooms of the many hospitals built under their specifications. A large number of sample panels of conductive floor coverings for hospital rooms were made up at the NBS or received from manufacturers and tested for electrical conductivity. The tests established the fact that the suggested addition of metal powders to cement mixes was not effective, and that the use of electrolytes such as are present in magnesium oxychloride floorings was effective only when some moisture was present. Rubber and linoleum floorings made conductive by the
presence of particular grades of carbon black were found the most promising.

Additional trials were made to determine what arc current was required to ignite grains of smokeless and of black powder under circumstances simulating the case when a broken wire connected to a 115-volt circuit might touch a highly conducting floor near a powder grain.

A related test also for the Corps of Engineers was the measurement of the electrical conductivity of ropes made with different fibers as substitutes for manila, which was no longer available. The results showed that the variations resulting from the use of different fibers were much less important than those resulting from changes in moisture content, and hence that no change need be made in the safety rules governing the use of ropes in contact with live electric circuits.

Electrical Battery Research

Before the Joint Army-Navy-MDRD Battery Advisory Committee was organized, several meetings of Army, Navy, and civilian personnel were held at the Office of the Chief Coordinator of the Navy Department. These meetings served to make apparent the existing lack of coordination in exchange of information on battery developments. Some poorly adapted types of batteries were being employed and apparatus was sometimes designed without giving adequate consideration to the type or size of battery needed to operate it. Accordingly, a joint directive, dated June 6, 1944, signed by Admiral Furer, General Ingles and Dr. Davidson, provided for the establishment of a Joint Advisory Committee on batteries. The NDRD representative on this committee was G. W. Vinal of the NBS staff, who served as Secretary of the Committee until the close of the war. With the expectation that the Committee would be continued, the recommendation was made that the NBS be represented directly on the Committee and Dr. Vinal was elected Chairman.

Storage Battery Separators

Shortages of rubber limited the use of microporous rubber separators in storage batteries. These are essential for the manufacture of batteries in the charged-dry condition which is the condition usually specified by the Armed Services for transportation and storage. Various substitutes were proposed and used to a limited extent.

At the request of the Bureau of Aeronautics, an NBS group under C. L. Snyder made life tests of various types of separators, including synthetic rubber, several kinds of plastics, glass fiber mats, and various wood preparations. In addition, experiments were made on combinations of plastic diaphragms with glass mats. Experience with electrolytically conducting plastic diaphragms in connection with dry cells and the silver oxide battery was a guide, but the conditions of using these thin (0.001 inch) diaphragms in strong acid introduced other problems. Diaphragms of certain plastics sandwiched between layers of fibrous glass assembled at the NBS gave satisfactory performance, outlasting some of the regular types. Two manufacturers of glass mats made limited quantities of these separators.

Low-Temperature Dry Cells

The ordinary dry cell becomes inoperative at temperatures of about -20°C (-4°F). This is a limitation which becomes important in military operations where equipment is exposed to arctic temperatures or the intense cold of the stratosphere. Various attempts to depress the freezing points by the addition of glycol or the substitution of calcium chloride for the usual ammonium chloride employed in the electrolyte have been reported. The Japanese began such an investigation in 1936. None of these was successful, because of the high internal resistance of the cells and resulting low capacity.

On June 18, 1942, a conference at the Bureau of Ordnance was held to discuss the possibility of improving the performance of dry cells at low temperatures. The use of methylamine hydrochloride and other organic salts as a substitute for ammonium chloride was proposed by G. W. Vinal on the basis of some preliminary experiments made at the NBS. Arrangements were immediately made for a transfer of funds to start the project.
small pilot plant was set up at the NBS and the experimental production of dry cells was begun.

Preliminary tests showed that methylamine hydrochloride was better adapted to the purpose than the more highly substituted salts. Cells of the "D" size were made with the methylamine salt which had flash currents of 2.2 amperes at -30°C (-22°F) contrasted with ordinary cells for which no flash current at all could be obtained at this temperature. It soon developed, however, that the shelf life and capacity of these cells was unsatisfactory. Then followed a long series of experiments by E. Otto and C. K. Morehouse to improve the cells. It was believed at that time that the use of ammonium chloride should be avoided, because it crystallized out of solution at low temperatures. Various formulas were tried. Substitutions for the paste layer were made, including poly-vinyl alcohol, methylcellulose, carboxymethylcellulose, cellophane, etc., but still the performance of the cells was unsatisfactory. Later, it was found that the addition of about 15% ammonium chloride to the methylamine salt stabilized the cells, improved capacity and did not materially interfere with operation at low temperatures. Good shelf life over a period of 12 months was attained. The capacity at normal temperatures on the light industrial test is about 800 minutes which compares favorably with that of ordinary cells; at low-temperatures of -50° to -40°C, the output is less, but the cells are usable if not subjected to long continued heavy drains.

Improvements are still possible. Research on the flour-starch pastes used in ordinary dry cells and substitutes for them showed that the output at extreme low temperatures can be increased fivefold by using the sodium salt of carboxymethylcellulose in place of the starch-flour paste. Some increase in capacity is obtained also at ordinary temperatures by this substitution. This again introduces the problem of obtaining satisfactory shelf life, but as a compromise the addition of some starch of flour improves shelf life very materially.

Throughout this investigation, the shelf life of the cells has been considered equally as important as obtaining satisfactory output at low temperatures. Materials and methods for the preservation of cells subjected to storage at high temperatures were also studied.

Low-temperature cells made at the NBS were supplied to the Bell Telephone Laboratories and were later produced in limited quantities by the National Carbon Company under contract from the Naval Ordnance Laboratory.

The Perchloric Acid Battery

The need for small, light-weight batteries for the radio-sonde, developed at the NBS for meteorological measurements up to 80,000 feet, having better electrical characteristics than dry cells and better operation at extreme low temperatures, led to the discovery of J. P. Schrodt and D. H. Craig of a practicable form of perchloric acid battery. This work was begun early 1940, and was prosecuted as an NBS project until early in 1941, when it was supported by the NDRC in connection with the proximity fuze, and later by the Bureau of Ships.

This battery is essentially a reserve type of battery, that is, it must be activated at time of use. It differs from the previously used conventional type of batteries in the following particulars:

1. The positive electrode is prepared by electrodepositing lead dioxide in solid non-porous form on an inert support. The negative electrode is also non-porous; it may be sheet lead.

2. The products of the electrochemical reaction are soluble and the active materials of the electrodes may be utilized completely.

3. It operates at low temperatures. For some purposes it has been used successfully at -60°C (-76°F).

4. The voltage characteristic of the perchloric acid battery under lead is much better than that of dry cells.

5. The perchloric acid battery, including the filling mechanism, gave 9.8 watt
hours per pound compared with 0.1 watt hours per pound for comparable lead-acid storage batteries. The radio-sonde type of perchloric acid battery weighs about 370 grams compared with dry-cell batteries for the same service weighing 663 grams.

6. The perchloric acid battery can be stored indefinitely in the dry condition without deterioration or loss in efficiency.

The one disadvantage of the perchloric acid battery, which limited its practical application, is the hazard of the acid if temperatures of 150°C (302°F) are encountered as a result of operation or accident. The Bureau of Mines cooperated by making extensive tests of the hazards involved. Much effort was devoted to finding a substitute acid which would be safer. Fluoboric acid is about 80 percent as effective and fluosilicic acid somewhat less effective, but none was found equal to perchloric acid.

Storage Batteries

Aircraft batteries of various types and sizes have been the subject of an extended investigation at the NBS under the supervision of C. L. Snyder. The work was supported by the Bureau of Aeronautics, Navy Department.

Operating conditions for batteries on aircraft are somewhat unusual. The batteries are subjected to extremes of temperatures. They are directly connected to constant voltage buses. Charging currents are sometimes excessive. They are subject to vibration, tilting, and sometimes they may be completely inverted. The service is therefore severe. One part of the Bureau's work has been the examination of batteries returned from the field after unsatisfactory service. Some failures of this sort could definitely be traced to poor maintenance.

Life cycling of aircraft batteries in the laboratory is automatically controlled and in general been continued 24 hours a day. This is necessary to maintain temperatures, particularly of those batteries subjected during test to high temperatures, 80°C (180°F), in an oven. This is dangerous work and every precaution has been taken to provide the necessary ventilation and other safety features.

Because of the urgency of this work and the unusual requirements, it was necessary to design and construct new control panels. The panels provide complete automatic control for the cycling of batteries at room temperature and at high temperatures. Continuous attendance is necessary, however, as on one occasion a battery under test developed a ground between one of its terminals and metal-shielded case, causing a fire.

As a more permanent installation to develop and extend this work, a new laboratory has been constructed and equipped in part by Navy funds. Six panels, and resistor units to dissipate the energy when the batteries are discharged, provide a unique equipment for storage battery testing. Power for charging the batteries is supplied by 12 motor-generator sets rated at 30 volts and a maximum current of 250 amperes each. These motor generators were provided by the Bureau of Aeronautics.

At the close of the war the Bureau had on hand a large number of experimental aircraft batteries awaiting test and this work is being continued. The objects of these tests are (1) to determine the serviceability of new materials and methods of construction, (2) to obtain batteries of the greatest possible capacity without increasing the size or weight over that of present batteries, (3) to discover the limitations imposed by widely varying conditions of temperature and other service requirements, and (4) to establish charging characteristics of these batteries on constant voltage, which become more critical as the internal resistance of the batteries is decreased.

Aircraft batteries are exposed to very low temperatures in field operations, so that low-temperature tests are necessary. For this purpose a refrigerated room is employed. Still lower temperatures are obtained in a cabinet which can be cooled to -60°C (-76°F). Ordinarily the low-temperature
tests are made at -40°C. High-rate discharges are required of batteries on airplanes and for the operation of various combat devices. Suitable testing equipment for this purpose was designed and constructed.

A vibrating machine carrying 4 batteries simulates the vibrations encountered on airplanes and is used as a test of structural stability of the batteries. Some tests of this character were made at temperatures as high as +80°C and as low as -40°C.

Tests of hundreds of vent plugs for airplane batteries were made to determine the angles at which the valves open and close and the pressures involved. This test is important because the modern combat planes climb at very steep angles.

A modification of the vent plug with a valve was developed, which employs a porous diaphragm through which the gas can pass. The development of gas pressure in a cell must be prevented, because the bituminous compound which is used to seal the covers is subject to plastic flow under pressure. Two manufacturers have undertaken the production of this new type of vent plug.

Other tests and investigations on storage batteries have covered case materials, rubber substitutes, separators, German torpedo batteries, American torpedo batteries, jet batteries, sea drome batteries, Japanese batteries, methods of heating batteries, and sealing compounds.

Internal Heating of Dry Batteries

Because dry batteries become inoperative at temperatures of about -20°C (-4°F) a method was sought to warm them internally by passing a small alternating current through them. Two methods were developed. The first serves to keep the battery in operating condition and ready for instant service although exposed to low ambient temperatures. For small "B" batteries exposed to an environment of -80°C (-184°F) an alternating current of 0.25 ampere serves to keep the battery up to about 75 percent of its flash current at 20°C (68°F) during 6 hours exposure.

The second method relates to restoring an inoperative dry battery to serviceable condition in a very short time, provided the battery is not completely frozen. A larger current which increases as the resistance of the cell diminishes is required. Unless the battery temperature is below -25°C (-13°F), the battery can be restored to serviceable condition in about 1 minute or less.

Zinc-Silver Peroxide Primary Battery

As part of the project on battery research supported by the Bureau of Ships, an investigation of silver cells was undertaken at the NBS by I. Dennison. The silver chloride electrode was first investigated but it was speedily found that conversion of the chloride to the peroxyde gave better results. Silver oxide can be oxidized and reduced between the peroxyde state and metallic silver. The output is therefore doubled over that from the chloride. The output of the larger sizes of the silver peroxyde battery was 21.0 watt-hours per pound compared with 6.1 watt-hours per pound for the lead-acid battery.

The discharge characteristics of silver peroxyde batteries are unusual in providing a very constant voltage under load. When the peroxyde is formed electrolytically, the charging voltage does not greatly exceed the discharge voltage and the efficiency is therefore high. This would be a great advantage in a secondary battery. Silver cells are better suited for use as primary batteries than as storage batteries. Silver peroxyde gives up its oxygen readily which proves to be both a blessing and a detriment. For cells to deliver enormously high currents, silver peroxyde is preeminent. A cell about the size of an octavo book delivered 2000 amperes.

By arrangement with the Navy, the Edison Storage Battery Company set up a pilot plant for the further development of silver peroxyde-zinc batteries. The large sizes were tested for torpedo propulsion shortly before the end of the war. Smaller sizes for other purposes were made also. For the
high rates of discharge, zinc negative plates made from powdered zinc were necessary to avoid passivity.

The ease with which silver peroxide is reduced makes it difficult to obtain good shelf life for batteries which are filled with electrolyte. Fundamental studies on the performance of silver peroxide electrodes and their behavior in various electrolytes are being continued. Ordinarily the electrolyte is a solution of potassium hydroxide, but there are advantages in using buffered solutions of sodium hydroxide. Turning to the organic field, ethylate solutions have been used successfully.

The separation of the electrodes is also important as a manner of preserving the cells during storage. Asbestos and various types of nonreducing plastics have been employed. Some of the latter have important applications to other types of batteries.

At the present stage of development, the shelf life of the silver peroxide-zinc battery at normal temperature is at least 6 months—the maximum period of test. Even at the temperature of (64°C) 130°F the battery shows promise of maintaining adequate shelf life.

Research on Battery Materials

The Bureau of Ships for several years past has supported a project at the NBS for the improvement of dry batteries through the utilization of new methods and techniques for studying the materials. Such problems as zinc corrosion, inhibitors, starch substitutes, manganese dioxide digestion, the evolution of gases, and the effectiveness of dry cell sealing materials were investigated.

Zinc Corrosion

It has been the practice of battery manufacturers for many years to incorporate a small amount of mercuric chloride in the paste of dry cells. This results in amalgamating the inner surface of the zinc. Chromates have also been used for the same purpose, viz., to decrease spontaneous local action at the zinc and thereby prolong the shelf life of the cells. A simple cell for the study of corrosion of zinc was devised. Hundreds of these can be stored in a moderate space and determinations made quickly and accurately. Specimens of zinc from various sources in a wide variety of electrolytes have been tested at high and low temperatures. The results showed that amalgamation which is reasonably effective at ordinary temperatures affords little if any protection to the zinc when the temperature is raised to 54°C. Failure of amalgamation at this temperature led to a search for inhibitors to stop the evolution of hydrogen.

Many commercial inhibitors are available for various purposes such as the pickling of iron and steel. Some are effective on zinc. In addition to these, other organic compounds were tested, some with satisfactory results when zinc alone was considered, but few could be used in dry cells because of increased internal resistance or the degradation of the starch paste. The starch-flour paste is itself an inhibitor. This led to an examination of the components of the paste. Pure starches of various kinds apparently have no inhibiting action. Flour on the other hand definitely has inhibiting properties. The inhibiting action of the flour was traced to the gluten it contains. The next step was to try gliaden. That, too, was an effective inhibitor. The amino acids, which are more soluble, were not. The use of gluten and gliaden remains for further investigation.

Manganese Dioxide

The interaction of manganese dioxide with other constituents of the cell, such as the electrolyte, the components of the paste and the carbon blacks, were the subject of accelerated tests. Digestions were made at various temperatures up to 100°C (212°F), followed by analyses of the resulting solutions for total manganese and available oxygen. Some very definite reactions were found.

Studies of the manganese dioxide used in dry cells have been made at the NBS, utilizing both the X-ray spectrograph and the
electron microscope. Much has been learned about the form and structure of the manganese dioxide and the changes it undergoes in the operation of the cell. Some typical oxides are beginning to be recognized as desirable for use in dry cells. The end products, such as hetaerolite, help to identify the reactions involved. The spectrographic microscope has also been employed to identify the "white compounds" formed in the paste when the cell is in use and those which appear as a result of deterioration in storage.

Gas Evolution

Several severe explosions have been reported in connection with buoy batteries and other large types of cells in sealed enclosures. This led to tests on various types of batteries encased in plastic, which was sprayed on to the batteries at the Naval Ordnance Laboratory. These batteries were stored in thermostatically controlled ovens at a temperature of 54°C (130°F) for periods of several months. Samples of the gas in the batteries were drawn periodically and analyzed by the mass spectrograph. Hydrogen was found as a primary product of corrosion. Oxygen tends to disappear. Residual air is determined from nitrogen and argon. The practical results so far attained indicates that dry cells encased in this plastic have much better shelf life than corresponding batteries not so encased.

Sealing Materials

The preservation of dry cells during shelf storage is in large measure dependent on the effectiveness of the seal. There is no standard for this and no generally recognized test for sealing materials. A shortage of rosin during the war made it imperative to seek satisfactory substitutes. The NBS was requested by the Bureau of Ships and by the manufacturers to investigate sealing materials and substitutes for rosin.

Starch and Starch Substitutes

Starch has the valuable property of forming a gel which serves as an electrolytic conductor and a separator between electrodes. It is subject to conditions in the cell which may cause oxidation and hydrolysis particularly at elevated temperatures. An extensive investigation was made of the properties of starch and flour and the gels which are made with them. Gluten, from which gliaden is obtained serves a most useful purpose in the cell, and may make possible the use of carboxymethylcellulose which has definite possibilities for improving the output of cells notwithstanding a definite disadvantage in promoting perforation of the zinc. Other substitutes for starch were tried with some success, but more work on this subject remains to be done.

Ballistics of Guns

This investigation was undertaken at the request of Division I, NDRC. Its purpose was to measure, as exactly as possible, what takes place in large guns from the instant the firing circuit is closed until the projectile emerges from the barrel; and as a second stage, the subsequent deceleration of the projectile over a short range. The information gained was to be applied to the design of a hyper-velocity gun by Div. I, NDRC, in which would also be incorporated the advances made by other groups who were studying powder erosion, protective chromium plating, gun liners, and similar problems.

The NBS project was assigned to H. L. Curtis, who had carried out similar investigations for the U. & Navy during World War I. The great 14-inch guns mounted on battleships were used in that work. For the present investigation guns of 37 mm, 3 inch and 90 mm caliber were chosen because the barrels could be equipped much more readily and the cost of operation was far less. Through the cooperation of the Naval Testing Basin, suitable laboratories and a range were constructed at Carderock, Md., which was very convenient for the Bureau staff and the members of the Geophysical Laboratory engaged in this work.

The large laboratory included indicating and recording equipment, and the response of each measuring instrument on the gun was
transmitted electrically to an oscillograph or other appropriate indicating instrument in the laboratory. A continuous record of the reading of each indicator was made on photographic film, usually held on the periphery of rapidly rotating drums 19 inches in diameter. The time sequence of all events was measured in milliseconds (in some cases with an accuracy of 0.01 m sec), zero time being the instant the firing pin started to move.

The measurements show that only one-hundredth of a second elapses between the ignition of the primer and the ejection of the projectile of a 3-inch gun. A detailed account of the apparatus and measurements is given in the report of Division I, NDRC. The measurements include the time of start of powder pressure; start of radiation; start of recoil; start of projectile; travel of projectile in gun; velocity and acceleration of projectile in gun; muzzle velocity; velocity and deceleration of projectile on the range; displacement, velocity and acceleration of gun in recoil; temperature and pressure of powder gas; jump of gun; strain measurements on the gun barrel; and pressure in recoil cylinders.

Magnetic Mine Countermeasures

During the early part of the war the Germans attempted to blockade the British Isles by an extensive use of their newly developed magnetic mine. This mine was sensitive to the vertical component of the ship's magnetic field, and to counteract it the procedure known as "degaussing" was developed by the Navy. As the war progressed and German magnetic mines became more sensitive, the problem of making the proper coil installations and of determining the correct currents became one of precise magnetic measurements and a large staff was assembled at the Naval Ordnance Laboratory to make these measurements. The correct calibration of all these instruments was a matter of much concern, and it was decided after conferences between NOL and NBS personnel that the problem could best be handled by a group at the NOL rather than by having the instruments submitted to NBS for calibration. The NBS agreed to loan personnel and facilities. Accordingly, R.W. Curtis of the Bureau staff was assigned to NOL to establish such a group. This group had to develop test apparatus and methods suitable for large scale testing of magnetic equipment with an accuracy which had never before been required outside of the laboratory.

Ships magnetic fields were determined on ranges which consisted of an array of range coils placed vertically on the bottom of a channel and connected to a battery of recording fluxmeters in the observation ship or station. These range coils were essentially pick-up coils consisting of a permalloy core with many thousands of turns of wire on them, all installed in a water-tight nonmagnetic case and connecting with a long length of heavy marine cable. As the ship passed over these range coils, the vertical component of the ship's field induced a voltage in them which was recorded on the fluxmeters. The range coil constant and the fluxmeter calibration together gave a measure of the value of the ship's magnetic field.

The calibration of the fluxmeters was simple, since the secondary of a mutual inductance in series with the input to the fluxmeter could be used to calibrate it on the spot by reversing a known current through the primary. However, the calibration of the range coils was troublesome since they were designed to be sensitive to external disturbances, and were permanently installed at the bottom of the channel. They were calibrated before installation by placing them in a solenoid of special design and reversing a known current in the solenoid. The response of the range coil under test was measured on a calibrated fluxmeter, or by more elaborate balancing circuits.

Attempts to operate this calibration equipment at NOL were unsuccessful since the extraneous magnetic disturbances caused by near traffic were too large to permit the necessary accuracy. A search for a magnetically "quiet" location resulted in the use
of the old floor-testing laboratory at the NBS. It is a wooden structure 40 by 40 feet in dimensions, located away from other buildings and roads. The building was modified by NBS for testing purposes. Apparatus suitable for quantity testing was installed and the calibration of range coils proceeded at a rapid rate, sometimes on a three-shift basis. The coils with their long heavy marine cables sometimes weighed 1,000 pounds apiece so it was necessary to install hoists for handling them. This equipment was in constant use during 1942 and was maintained as a test station until the middle of 1944, when the new "White Oak" laboratories of NOL became available.

The design and construction of the above-mentioned solenoids were expedited in several ways by NBS. The design was suggested by the standard inductance coils made by NBS. An aluminum tube was threaded with a precision double thread in an accurate lathe at NBS, and after it had been anodized, the threads were wound with enameled wire directly on the anodized aluminum. This made a rugged and accurate solenoid, which could be checked for shorted turns or grounds very easily. Its magnetic constants could be computed from the accurately known pitch of the winding. These solenoids were shipped to many parts of the world and by maintaining their accuracy did much to assure uniformity of magnetic measurements throughout the world. The first models were made in the gage shop of NBS under the direction of W.B. Topping. After he had worked out the technique later production was successfully carried out by outside contractors.

Constant Depth Mine

Early in the war the Naval Ordnance Laboratory requested the NBS to undertake the design of a marine mine which would remain at a definite depth in the water for a day or two. Attempts had been made to design such a mine during World War I but without success. This project, the details of which are classified as "secret," was assigned to Charles Moon and R.L. Driscoll of the Bureau staff and they succeeded in making a satisfactory design. This was tested in a tank at the Navy Yard and at sea, and in both places it operated continuously for the required time.

Magnetic Thickness Gages

In 1937, Abner Brenner of the Bureau's staff invented an instrument for measuring the thickness ([1] of magnetic coatings, e.g., nickel, on a nonmagnetic base metal; ([2]) of nonmagnetic coatings, which may consist of metal, paint, or enamel, on steel; ([3]) of less magnetic coatings, e.g., nickel, on steel. The device consists of a permanent magnet, the attraction of which to the surface tested is measured with a spring balance. In 1938, the American Instrument Company, Silver Spring, Md., started the manufacture of this instrument, designated as a "Magnegage." These gages are calibrated at the Bureau for specified fees, which include the cost of supplying standard thickness samples issued with the calibrated gage.

Up to 1940, less than 200 of these instruments were submitted, but since then over 2,000 have been calibrated. They have proven valuable in the non-destructive testing of coatings on many military supplies. Their use not only expedited the production of acceptable equipment, but also conserved scarce metals by avoiding the use of unnecessarily thick coatings. During the last few years, the fees for this testing (returned to the U.S. Treasury) amounted to about $15,000 per year.

The same principle was employed in a gun-barrel Magne-gage, designed to measure the thickness of chromium in lands or grooves of guns 3 inches or more in diameter. Two of these gages were calibrated for use at the Washington Gun Factory and the Naval Gun Factory at Pocatello, Idaho. A similar gage was designed and calibrated for measuring the thickness of chromium in caliber 50 barrels. This gage was completed about V-J day, and was delivered to Springfield Armory.

In certain phases of the atomic bomb project, equipment plated with thick nickel coatings (0.006 inch or more) was employed. Assistance was given in the design of two special Magne-gages for measuring these coatings.
Specifications for Electrical Supplies

Purchases of electrical supplies by the Government expanded so greatly during the war that an urgent demand for suitable specifications came from both industry and the Government. The Government's interest arose from the desire to obtain supplies of satisfactorily high quality, while the industry demand was prompted by the necessity of standardization of requirements by the various purchasing agencies of the Government if articles were to be manufactured in large quantities and supplied from stock. Twenty-three new specifications for electrical supplies, ranging from blasting apparatus and distribution transformers to sockets, switches, and receptacles, were formulated during the war. In addition, for the purpose of conserving critical materials such as rubber, copper, zinc, cadmium and nickel, there were formulated during the defense and war periods about 50 Emergency Alternate Specifications and 25 War Amendments to Federal Specifications for electrical supplies.
8. Aerodynamic and Aircraft Problems

The work of the National Bureau of Standards in the field of aerodynamics has been concerned mainly with basic research. During the war, considerable work was done in the field of the aerodynamic properties of missiles. At the same time, special problems concerned with aircraft engines, auxiliary engine equipment, oxygen equipment, and aircraft instrumentation were investigated.

Aerodynamic Investigations

For some years prior to the war the NBS cooperated with the Army Ordnance Department in bomb and projectile development by measuring the aerodynamic characteristics of model and full scale missiles in the Bureau's wind tunnels. This information is necessary in predicting and improving the performance of missiles in flight. The work was greatly expanded during the war to include the requirements of the Bureau of Ordnance, Navy Department, and the OSRD. To meet these needs a new 6-foot atmospheric tunnel of the closed-circuit type was designed and constructed on the Bureau grounds, together with apparatus for determining the damping and trim characteristics of bomb models and an improved device for accurately and rapidly determining the drag of models when yawed.

Numerous missile designs were examined by means of wind tunnel tests, and as far as possible the optimum performance of each missile was determined within its specified dimensional limitations. In urgent cases, the decision by the Armed Services to proceed with the manufacture of modification of certain missiles was based on the results of the wind tunnel investigations alone and the responsibility thus placed on the NBS was considerable.

Most of the Bureau's wind tunnel personnel were employed continuously on the missile research program throughout the war. The resulting data were summarized in part in a two-volume report issued by the Aberdeen Proving Ground and represent a substantial contribution to exterior ballistics. The service missiles studied included an early design of the Army "Bazooka" for which a "ringtail" fin system giving improved performance was developed; the Navy 326-pound, 650-pound and 850-pound aircraft depth bombs; the Navy 1,600-pound armor piercing bomb; mortar shells ranging from 60 mm to 155 mm in diameter; and various German, Italian and Japanese missiles. Data obtained in the investigation of these foreign missiles proved helpful to the Eighth Air Force in adapting American bombng tables for use in the appropriate return of captured German bombs.

Determinations of Magnus force (conducted in the Bureau's 4 1/2-foot wind tunnel, using a 4/5 scale internally-driven model of a Navy 5-inch spin-stabilized rocket) are believed to be the first made for a projectile of this type in the wind tunnel. The Magnus force makes the spinning rocket deviate from its normal trajectory, just as a spinning baseball follows a curved path.

The Naval Ordnance Development award was conferred on an NBS aerodynamics group headed by R. H. Heald in recognition of its contributions to the war effort. The group also received special commendation from the Army Ordnance Department.

Research work on turbulence carried out at the NBS in cooperation with the NACA furnished much of the information necessary for the design of low-turbulence wind tunnels. Such tunnels, constructed in this country and abroad, proved to be an indispensable instrument in the study and development of laminar-flow airfoils, which came into use during the war and materially increased the speed of fighter planes used by the United States and our Allies.

Shortly before our entrance into the war an investigation of laminar boundary layers, directed by H. L. Dryden and G. B. Schubauer, was conducted in the NBS low-turbulence wind tunnel with the cooperation of the NACA. This investigation yielded some important and far-reaching results. Because of the smooth and steady flow conditions which could be maintained in this
tunnel there appeared a hitherto unnoticed phenomenon known as laminar-boundary layer oscillations. A detailed study of these oscillations completely verified a stability theory developed by the German school of theoretical investigators, but which had been rather discredited by experimental aerodynamicists. The results of the Bureau's work together with later contributions from other laboratories led to a fairly complete understanding of the transition from laminar to turbulent flow. While the general design methods for producing laminar-flow airfoils were known prior to this work, the discovery of laminar boundary-layer oscillations and the establishment of a sound theory of stability placed the design methods on a firmer footing and further defined the conditions under which laminar flow could be obtained.

Other war and related activities carried on by the Aerodynamics Section included the calibration of numerous instruments for the measurement of air velocities on shore and on shipboard; measurement of the ventilation supplied by blackout screens for the office of Civilian Defense, the testing of electric fans for the Maritime Commission and the determination of arming time of bomb fuzes of various types.

Aircraft Engines

Combustion Research

A program of research on combustion in high-velocity air streams, begun in January 1943 under E. F. Flock and sponsored by the Bureau of Aeronautics, Navy Department is still in progress. The project has included the development of complete burners of two general types, together with studies of the factors influencing combustion.

From tests of many experimental burners of the type applicable in turbo-jet engines and gas turbines, the following facts were evolved: (1) velocity distribution at the burner inlet has an important effect on burner performance; (2) a burner designed to operate efficiently on one fuel will usually burn other fuels less efficiently; (3) the primary air, constituting from about 1/4 to 1/20 of the total air, must be slowed down in the combustion chamber to approximately 50 ft sec; (4) good mixing of flame gas with secondary air can be accomplished only at the expense of pressure loss within the burner; (5) the characteristics of the fuel spray affect both ignition and subsequent combustion and (6) the combustion efficiency of most burners decreases with increasing air-fuel ratio.

Determination of combustion efficiency by exhaust-gas analysis is highly desirable, but conventional methods of analysis are not suitable because of the large excess of air. A special scheme of analysis, involving determination in a combustion train of the total unoxidized material in the exhaust gas sample, has been developed and found satisfactory. Two other laboratories are known to have adopted this method.

The rate of carbon formation, under arbitrarily chosen operating conditions, has been measured for 16 fuels, including fuel oils, kerosines, gasolines and pure aromatic compounds, in each of 3 different turbo-jet burners. This rate was found to vary linearly with carbon-hydrogen ratio in all tests to date. The design of a small burner for determining the relative rate of carbon formation for various fuels on a laboratory scale is being attempted.

Exhaustive performance tests, over the entire range of operating conditions which could be achieved with available facilities, were conducted on one combustion chamber furnished by the British Air Commission and on 2 captured German combustion chambers. Results of these tests were furnished to those interested in designing similar burners in this country.

After many trials of an empirical nature, combustion chambers for 4-inch and 7-inch ram jets have been evolved. These consist primarily of an injector for liquid or gaseous fuel and a flame holder which maintains a small flame as a pilot to ignite the bulk of the mixture. When discharging at atmospheric pressure, these burners operate smoothly over a wide range of air velocities and mixture ratios. Tests at altitude remain to be made elsewhere.

In this type of burner the distance of flame travel laterally from the pilot flame and the length of the burner have been shown
to be related. Although this relation is not yet fully understood, it seems certain to have an important bearing on burner design. Experimental work has included trials of many types of fuel injectors and pilot flame holders; static pressure surveys along the burner with the flame holder in various positions; and studies of the effects of inlet velocity distribution, inlet air temperature, and various discharge nozzles.

The combination of a turbo-jet burner, followed in series by a ram-jet burner, was studied as a possible means for thrust augmentation in jet-propelled aircraft. On the basis of these results, a full-scale installation was designed. The drawings have been forwarded to the Naval Air Materiel Center, Philadelphia, for construction and subsequent trials.

Since this program was undertaken before industry in general became interested in jet propulsion, the staff acquired a background which could be transmitted to others during their many visits to this Bureau. It is felt, therefore, that one of the major contributions of the combustion-chamber research program has been the strictly intangible one of passing along both the useful information obtained and warnings against leads which have been followed without material success. Monthly reports of progress were submitted to the Bureau of Aeronautics which distributed 50 copies to interested industrial laboratories and to other military groups.

**Oxygen Boost at Altitude**

Prior to our entry into the war, some German aircraft shot down over England were found to have auxiliary tanks and supply equipment which were believed to have carried oxygen in combined form for supplementing the normal quantity supplied to the engine by the supercharger. This additional oxygen could be used when bursts of speed were required or when it was desirable to increase the rate of climb and the normal ceiling of the airplane.

Since such extra performance was highly desirable in military aircraft, the Bureau of Aeronautics of the Navy Department requested that a survey be made of oxygen-bearing compounds which might be useful for this purpose.

Certain organic nitro compounds, oxides of nitrogen, hydrogen peroxide solutions, and pure oxygen were found to be most promising, with liquid oxygen the most attractive of all.

Research effort was therefore concentrated on pure oxygen, and testing was begun with a single-cylinder water-cooled engine. In the earliest tests gaseous oxygen was injected, but the knock increased greatly without much increase in power. Then liquid oxygen was injected, together with the extra fuel needed to consume it, with startling results on engine performance. Even when the engine was knocking heavily prior to the injection of the liquid oxygen, the knock would disappear and the power would increase markedly as soon as injection began.

Testing was then shifted to a 4-cylinder air-cooled engine for light aircraft, with encouraging results. Since the higher powers meant hotter cylinders, simultaneous injection of internal coolants such as water, aqua ammonia, alcohols, and alcohol-water mixtures was tried and found effective. After more than 100 hours of operation with oxygen injection, the engine showed no undue wear and the development was considered sufficiently advanced for full-scale application.

NBS representatives collaborated with members of the staff of the Aeronautical Engine Laboratory, Naval Air Materiel Center, Philadelphia, in the full scale tests. These tests involved 4 different types of radial air-cooled engines on the ground and 2 in flight. Results of the final flight tests on an F4U-1 fighter aircraft with simultaneous injection of liquid oxygen and water-alcohol were as follows: Total weight of boost system, including 100 lb of liquid oxygen (sufficient for about 15 minutes of operation), 179.1 lb; depending on altitude (28,000 to 35,000 feet), the forward speed was increased by 15 to 40 mph and the rate of climb was increased by 200 to 500 ft per min; and there was no evidence of excessive engine wear. In the course of the tests 19 tons of liquid oxygen were consumed without accident.

Although the feasibility of boosting engine power at altitude with liquid oxygen was demonstrated, the process was not used in
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combat by our forces. However the British
did use "laughing" gas in a similar way and
the Germans used hydrogen peroxide in rocket
fighters. The concentration of effort upon
jet-propelled aircraft was a potent factor
in the shelving of possible schemes for in-
creasing the speed of conventional aircraft.

Calibration of Metering Jets

The former method for testing the flow of
the fuel metering jets of aircraft carbure-
 tors involved the use of flammable gases
in open vessels. After a service fire in such
equipment, the National Bureau of Standards
was requested by the Bureau of Aeronautics,
Navy Department to develop an instrument
which would serve the same purpose, yet be
free of fire hazard. The comparator which
was developed to meet this need utilizes com-
pressed air as the test fluid. This instru-
ment is not only free from fire hazard, but
has also proved more accurate and about 6
times as fast as the former equipment.

The comparator has been in service in Navy
shops since the beginning of 1944, and no re-
port of unsatisfactory performance has been
received. Many jets found by tests in the
field to be wrongly stamped have been return-
ed for check, and in every instance the re-
results obtained in service were confirmed.
The manufacturer has furnished 160 instru-
ments to the Navy, 27 to the British on lend-
lease, and several to private concerns.

Carburetor Jet Boring Tools

The supply of replacement metering jets
for aircraft carburetors in every size which
might be needed by each overhaul station be-
came so critical that the NBS was requested
by the Bureau of Aeronautics, Navy, to de-
vop a set of tools with which any jet de-
sired could be made from a blank or from an
undersize jet.

Tools to cut jets of Types B and C were
developed for this purpose. These tools are
half-round cutters shaped to conform to the
dimensions of factory-made jets. Since each
tool is steadied over a full half of its cir-

cumference, the tendency to chatter is much
less than with a conventional fluted reamer

and jets produced successively with a given
tool are very uniform as to flow character-
istics. Thousands of laboratory tests have
shown that even an inexperienced lathe oper-
cator can bore jets, to the size stamped on
the tool in terms of gasoline flow, within
the allowable tolerance of plus or minus 1
percent in flow, with rejections not ex-
ceeding 5 percent of the jets cut. The tools
work equally well in solid blanks or in pre-
bored jets. Fifty complete sets, each con-
taining 164 tools, were ordered by the Navy.

Fuel System Flow Characteristics

The flow characteristics of aircraft fuel
systems and their components have been under
investigation at NBS since 1936, as a part of
a general investigation of aircraft vapor-
lock problems. The entire program has been
sponsored by the CFR Aviation Fuels Division
(an agency of Coordinating Research Council,
Inc.) and financed mainly by the aircraft and
petroleum industries.

The first phase of this study was concerned
with the resistance offered by tubes, fit-
tings and valves to the flow of liquid gaso-
line and of mixtures of gasoline containing
up to 50 percent of vapor by volume. Because
of this work, designers are now able to pre-
dict the resistance of any proposed fuel sys-
tem from fuel pump to carburetor. Additional
tests were made in 1941, to determine the ap-
PLICABILITY of the gasoline data to fluids
of higher viscosity, with particular refer-
ence to so-called "safety fuels" and hydrau-
lic oils.

The second phase of the study, begun in
October 1941, was the evolution of a safer
method for evaluating the vapor-handling ca-
pacity of aircraft fuel systems. In this
method, measured volumes of air were injected
into the gasoline, the temperature and vapor
pressure of which were controlled and known.
The initial assumption that air and gasoline
vapor have identical effects upon fuel-system
capacity was supported by the experimental
data.

In June 1942, the Bureau of Aeronautics
requested evaluation of optimum fuel-line
size and engine fuel-pump efficiency. Tests
of optimum line size already had been made by the air-bleed method on 3 simple fuel systems differing only in tubing size, and the results verified the empirical limits on flow rate in current Navy fuel-system specifications. Similar tests were made during 1943, on replicas of fuel systems from two service airplanes (F4U and B-25C). The capacity of a single fuel pump was also investigated by the air-bleed method.

The third phase of this work, undertaken in December 1943, was an investigation of current military fuel pumps under conditions designed to determine directly the separate effects of air and vapor on capacity. All available engine-driven service fuel pumps were tested on air-free hydraulic oil over a wide range of inlet and outlet pressures, both with and without relief valves, to ascertain their basic characteristics with respect to cavitation and slippage in the absence of air and vapor. The measurements were repeated in the same system with air-free gasoline of known vapor pressure. Measurements on one representative pump were made with 3 other fuels of widely different vapor pressures. The results permit prediction of the performance of a fuel pump at any altitude from a single determination of the entrance loss inherent in the pump (cavitation pressure), and the vapor pressure and air content of the fuel to be handled.

Temperature Studies

In 1933, when certain Navy patrol planes were being grounded owing to engine overheating, measurements of engine and accessory temperatures in flight conducted by NBS personnel served to diagnose the trouble and to determine when adequate changes had been made in the cowling and cylinder baffles. Because of this experience, similar surveys were made on many other types of naval aircraft, and presently the Navy Department made such temperature measurements an essential part of the acceptance tests of new naval aircraft. The first specification covering "Temperature measurements of aircraft engine installations" was approved in January 1938. This has been modified from time to time and is now being adapted to include jet engines.

Members of the NBS staff conducted these temperature surveys with assistance from Navy personnel until 1943, when they were taken into the Naval service. Since then, the work has been conducted by the Navy Flight Test Section at Patuxent. Other NBS personnel have continued to assist in the design, procurement, calibration, and installation of temperature-measuring equipment, and to collaborate on various power-plant and flight-test instrumentation problems.

Electrical Brush Wear

In 1941, at the request of the Bureau of Aeronautics, work was started on the brush-wear problem. At that time brushes on certain aircraft motors and generators were wearing so rapidly, under very high altitude conditions, that their life was often only a matter of minutes. First tests were made on aircraft generators in an altitude chamber using brushes submitted by various manufacturers. Such tests were continued and were supplemented by various bench tests. The work of the NBS was coordinated with that of other laboratories and, as a result of the combined effort, brushes with satisfactory life at altitude were developed before the end of 1942.

While the improved brushes met immediate military needs, the empirical nature of the solution was generally recognized and the NBS was asked to undertake a further study of the causes and prevention of excessive brush wear. Since early 1944, a systematic exploration of the conditions which are associated with rapid brush wear has been conducted, in the expectation that the data obtained will serve as a basis for evaluating the various factors involved. To expedite the investigation, 3 additional test units of improved design were constructed and put in operation during 1945.

Ignition Systems

Work for the Bureau of Aeronautics on aircraft engine ignition had been going on for
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October 1940, the Army Air Corps pointed out that current specification requirements for explosion-proof motors, being based on industrial motors, were unnecessarily severe when applied to the light-weight, small motors used in aircraft. At their request, the NBS developed during 1944, equipment for testing aircraft motors which were designed for use in hazardous gasoline mixtures, and tested 11 motors. For these tests the motor was mounted in a chamber containing an explosive mixture of gasoline vapor and air. The mixture within the motor casing was ignited by means of a spark, and the requirement was that sparks of flame from within the motor should not cause an explosion of the surrounding mixture.


ten years before the attack on Pearl Harbor. In this work close collaboration had been maintained with the Aeronautical Engineering Laboratory of the Naval Aircraft Factory, Philadelphia, and this was continued during the war.

The development of spark plugs embraced development of experimental types; studies of mechanical, thermal, and electrical characteristics; development of test instruments and testing procedures; and calibration of instruments for use in field service. These activities included measurements of thermal expansion of center electrodes, measurements of strength of the spark plug shells, studies of electrical flashover in the barrel, and development of an instrument for measuring gas leakage, and calibration of all "Nafoteles" purchased by the Navy. (The Nafotel is an instrument developed earlier at NBS, primarily for the testing of used and reconditioned mica spark plugs.

The work on ignition cable was largely testing for qualification. This specification was to a considerable extent based on results of earlier experimental work at the NBS.

Type tests were carried out on magnetos, under an Army-Navy specification, this specification also being based on earlier NBS work. Tests were made on other spark generators, such as spark coils and circuits involving the use of vacuum tubes. Some special assignments were carried out, including an investigation of ignition system performance in flight, a study of breaker contact phenomena, effect of a booster coil on altitude performance of a magneto, and tests of insulating materials for use in magnetos.

Tests were made on spark plugs, ignition cable, and magnetos from the ignition systems of captured enemy aircraft, as well as on spark plugs and magnetos of British design and manufacture.

The work described above was transferred to the Naval Air Materiel Center, Philadelphia, when facilities for carrying it on became available there in the fall of 1944.

Low-Tension Electrical Equipment

In the period from 1938 through 1941, numerous problems involving the correlation and standardization of low-tension electrical equipment for aircraft service were investigated for the Bureau of Aeronautics. For example, a theoretical study was made of the relationship between voltage and weight of aircraft electrical systems. Other experimental studies, represented only by reports, are illustrated by the following: (1) The determination of the safe-carrying capacity of cable for continuous and for transient currents under high-altitude conditions; (2) the investigation of voltage-current relations for break arcs with large currents; and (3) the development of inductance standards for circuit breakers. During this period, specifications and sources of supply were developed for improved low-tension cable, permitting the use of insulating materials other than rubber.

After Pearl Harbor, the more fundamental problems were laid aside temporarily, and major effort was directed to the qualification testing of cable, circuit breakers, magnetic contactors, and rheostats under existing specifications; and to performance testing of these and other electrical components, such as connectors and switches, in order to develop improved specifications and overcome difficulties encountered in service. During 1945, this qualification and performance testing was gradually taken over by the Naval Research Laboratory, as their facilities and equipment became available.

Explosion-Proof Motors

In June 1940, the Army Air Corps pointed out that current specification requirements for explosion-proof motors, being based on industrial motors, were unnecessarily severe when applied to the light-weight, small motors used in aircraft. At their request, the NBS developed during 1944, equipment for testing aircraft motors which were designed for use in hazardous gasoline mixtures, and tested 11 motors. For these tests the motor was mounted in a chamber containing an explosive mixture of gasoline vapor and air. The mixture within the motor casing was ignited by means of a spark, and the requirement was that sparks of flame from within the motor should not cause an explosion of the surrounding mixture.
During the next two years, testing was continued under the joint auspices of the Army Air Forces and the Navy Bureau of Aeronautics, and 23 motors were tested. Work here on this problem was discontinued in July 1943, and the experimental apparatus was transferred to Wright Field.

**Induction System De-icing**

The induction system de-icing project was set up by the NACA Committee on Power Plants for Aircraft in September 1940, primarily because of icing difficulties experienced by the commercial air lines. Under certain atmospheric conditions, troublesome ice formation occurs in the intake of some carburetors even at summer air temperatures. The significance of this problem to military as well as civil aviation was obvious.

The de-icing project called for rather special facilities not readily or promptly available anywhere else. The NBS offered the use of its altitude laboratory, the basic mechanical equipment of which was adequate for the early steps of the investigation and served the purpose until the project was transferred to the NACA Cleveland laboratory early in 1944.

When the facilities of the altitude laboratory were offered for the research, it was contemplated that the NBS would be responsible for the operation of the exhausters, refrigerating machinery, and power supply while the NACA subcommittee would organize the research project, furnishing the personnel and special equipment for the purpose. As the preparations progressed, however, it appeared that the NBS could more readily organize the whole project, and funds were furnished by the Army and Navy as well as the NACA. The latter organization also detailed engineers to the de-icing staff for various periods.

Preliminary observations showed that ice formation in the intake system can occur under a wide variety of conditions and can result in complete engine stoppage in a very few minutes under some conditions. Many observations were made and photographs taken in the preliminary study to delimit the range of hazardous conditions.

The portion of the program completed at the National Bureau of Standards under the supervision of L. B. Kimball included the following general phases of the problem.

1. Range of atmospheric conditions under which icing can occur and those under which it is hazardous.
2. Design factors of the carburetor and intake passages which will minimize or prevent ice accumulation.
3. Effectiveness of heat in eliminating ice or preventing ice formation.
4. Effectiveness of de-icing fluids such as ethyl, methyl, and isopropyl alcohol in eliminating or preventing ice formation.
5. Tests of many proposed icing indicators designed to warn the pilot of incipient ice formations or to actuate preventive measures. No effective device was discovered along this line.
6. Studies were made of the amount of free water per unit volume of air to be expected under rain conditions.
7. A limited study was made of means for preventing entrance of rain into the carburetor without losing the "ram" effect of the forward velocity of the plane.

The work at the NBS covered several different carburetor and intake designs and showed that design has marked effects on the severity of icing conditions. The program is being continued at the Cleveland laboratory of the NACA in expanded form, covering in more detail the field already mentioned and including new intake designs as they are developed.

**Oxygen Equipment**

The Aeronautics Instruments section headed by W. G. Brombacher played an active role in the development of oxygen equipment for the use of personnel in aircraft. Operating on funds supplied by the Bureau of Aeronautics (Equipment and Materials Branch), Navy Department, evaluation and performance tests were made on a large number and variety of experimental and production items of oxygen.
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equipment. Significant improvements were contributed and advice was given to the authorities responsible for procurement.

Before the war, on NBS recommendation and designs, the Navy had equipped many of its aircraft with oxygen dispensing regulators which supplied pure oxygen to the user only during inhalation, and only to the extent required. As descriptive of its performance, this type was called the "demand" regulator. As a parallel development, for longer range aircraft, work was done up to 1944, in testing and improving the mechanical operation of rebreathers, in which the user breathes oxygen in and out of a flexible bag and a small supply of oxygen is added from a tank or from a chemical source, to replace the amount actually consumed. A chemical absorbs the carbon dioxide and some of the water vapor exhaled, and in later models, the same chemical supplies the oxygen.

As an improvement to supplant both the demand regulators and the rebreathers, a program of development was recommended and actively pursued culminating in 1943, in a new type of regulator which is now standard equipment with both Army and Navy. This type, called the "diluter-demand" regulator, automatically draws in a tolerable proportion of air with the oxygen supplied during each inhalation. The proportion of oxygen is varied with change of altitude by an aneroid controlled valve. Experiments were made in 1940, on two experimental types, in one of which the oxygen, flowing through an injector, sucks in the air. In the other, air is drawn in by the user's breathing suction only. The former type was recommended as most likely to give suitable performance. After it was found in 1941, that the Germans had already made reasonably good models of the former type, the line of further development was mainly improvement of details.

The concentrations of oxygen physiologically desirable for various altitudes were computed on the basis of physical gas and vapor laws. Charts showing the concentration required at various altitudes to simulate respiratory conditions at other altitudes during breathing of ambient air were constructed, circulated and later published.

Tests and investigations were made on practically all components of oxygen systems and associated equipment. Approximately 800 reports were issued during the war period. Representatives of the Aeronautic Instruments section participated in more than a hundred conferences on research and development projects of the Navy Bureau of Aeronautics, the Army Aero Medical Laboratory, various sections of the NDERC, and the Committee on Aviation Medicine (Subcommittees on Anoxia and Oxygen), and with various manufacturers. Much work was done in advising and aiding in the preparation of Army-Navy performance specifications.

Steel cylinders for storage of compressed oxygen were tested for mechanical strength; the reaction forces to be expected when charged cylinders were ruptured or punctured were calculated; and tests were made of mounting brackets to hold the cylinders under these conditions. Studies were made to determine the most practical arrangement for transferring oxygen from large storage cylinders to smaller aircraft cylinders by the cascade method. The conditions under which explosions could be caused in oxygen lines were investigated. Sudden applications of high pressure oxygen often cause explosions if oil, gasoline, starch, or combustible fibers are present.

Regulators

The regulators are the most critical elements in the oxygen systems; the proper functioning of the entire system is literally vital to high altitude flyers. More than 800 regulators, representing 80 different experimental and production models were critically evaluated for suitability, with special tests bearing on performance, construction and materials.

In the usual demand-type regulators, flow occurs in response to suction created by the user. In a variant of this type developed at the Bureau, the regulator serves as a pressure reducer supplying oxygen at a low pressure of a few tenths of an inch of water. Thus the user is assured of oxygen upon inhalation even though leaks exist around his mask. This type was called the safety-pressure
regulator, since the object is to insure safety by preventing the inward leakage of air into the breathing apparatus.

In performance tests of diluter-demand regulators, it is necessary to determine the concentration of oxygen delivered by the regulator at various altitudes and under various conditions. The simplest mechanical way to do this is to measure two of the three flow rates: (1) oxygen supplied to the regulator, (2) air drawn into the regulator, and (3) the air-oxygen mixture delivered. Equipment based on this method was designed and constructed, in which the regulator under test is mounted in an altitude chamber.

An improved linear-resistance type of flowmeter having much more suitable properties was developed, in which crinkled glass wool packed into a canister is used. The volume of gas flowing through the glass wool is directly proportional to the differential pressure across it, which is indicated by a manometer or dial gage. Since the pressure drop is determined by the viscosity, which is independent of pressure, the calibration of the flowmeter does not change with altitude.

Designs were supplied to manufacturers and thorough tests were made on the first 25 test units bought by the Navy. Several hundred test sets of this design were manufactured on A-N specifications.

**Masks, Breathing Tubes, Connectors**

The development of acceptably leak-tight and comfortable masks was one of the most difficult problems in the oxygen program. The NBS did not design masks, but tested and evaluated many samples submitted.

One of the common failings in masks was the freezing of the exhaust valves, or blocking of the ports by accumulation of ice or frost when used at low temperatures. To facilitate low temperature tests, a cold-chamber was designed and constructed in which the individual wearing the mask had his head and shoulders in the refrigerated atmosphere. Solid carbon dioxide was used to cool the chamber; and it was found that the subject could readily detect a failure due to freezing of a mask valve by the inward leak of CO₂ which in such high concentrations can be easily detected by smell or taste.

More than fifty types of oxygen masks were studied with reference to low temperature performance, fit, comfort, suspension, goggle interference, leakage and flow resistance.

The use of positive pressure regulators required an exhalation valve which would automatically adjust its opening pressures to be slightly above the pressures delivered by the regulator. Such a valve was designed, constructed, and disclosed to the Army and Navy. In it, the regulator pressure acts on a flexible bellows or diaphragm, with effective area slightly greater than that of the exhaust valve, to close the valve and to hold it closed against an equal pressure in the mask. When exhalation begins, a check valve in the mask inlet port closes, permitting the pressure in the mask to rise sufficiently above that in the regulator to overcome the differential loading and open the valve. Thus the mask pressure is maintained relatively constant at the set valve, during both inhalation and exhalation. At lower altitudes, the delivery pressure is reduced to very low values and the equipment operates without abnormal effort by the user. Large numbers of balanced valves and check valves for masks to be used with positive-pressure regulators have been procured by the Army and Navy.

A simple device which enabled a person to test his own oxygen mask for leaks met with much favor. This consisted of a small extensible bellows connecting two end plates, in one of which a connector was installed. When connected to the mask and suspended by the top plate, the weight of the bottom plate created a suction. The rate of the leak was measured by the expansion of the bellows while the user held his breath. More than a hundred thousand of an Army modification of the NBS design of these pocket-size testers were procured by the Armed Services.

**Liquid Oxygen**

The containers for liquid oxygen weigh much less than gaseous containers and the space requirement is also considerably less. Until recently, these advantages have been offset by the lack of manufacturing facilities, transportable containers, and suitable equipment for converting liquid oxygen to gas.
as needed. Because of these adverse factors, little serious work had been done on development of aircraft equipment for utilizing liquid oxygen since the last war, although the Army used liquid rather than compressed gas until 1935.

In 1942, a report was submitted to the bureau of Aeronautics outlining a design for a converter considered more suitable for aircraft use than others then available, and a program of experimentation, construction, and testing was initiated. The war ended before these developments were put into service use, although small contracts had been placed for commercial manufacture, based on NBS designs, for both the Army and Navy.

About half of the weight of the full converter is oxygen, as compared to about one-fifth for a steel cylinder. The heat energy to evaporate and warm the liquid is taken from the atmosphere. Filling may be done through a long insulated hose, leaving the converter in the aircraft.

Water in Oxygen

In 1941, the Bureau of Aeronautics asked the National Bureau of Standards to assist in determining reasonable limits of dryness of the oxygen supplied to airplane pilots, and means of determining when these limits were exceeded. At that time it was said to be not uncommon for the oxygen equipment of the pilot to clog with ice at high altitudes, and one or more planes were believed to have been lost when pilots became unconscious as the result.

With the cooperation of the Southern Oxygen Company, which opened its plant for inspection, it was found practicable to dry the gas after compression to a few micrograms of water per liter, but the drying of the cylinders sufficiently to prevent the later contamination of the gas proved more difficult. It was found necessary, in the beginning at least, to test each cylinder of gas individually; and this was an all but impossible task by existing methods. A method, originally devised by E. R. Weaver for detecting moisture in gases in catalytic processes where water is a "poison," but not previously made quantitative for low humidities, was adapted to the purpose. It depends on the fact that the electrical resistance of a film of an electrolyte, such as phosphoric acid, in equilibrium with a gas containing water vapor increases rapidly as the water vapor per unit volume decreases. The quantity of water in a unit volume of a gas mixture of given composition can be changed by changing the pressure. By adjusting the pressure of a sample of gas with an unknown moisture content until it produces the same electrical resistance in the detecting film as does a known standard, the composition of the unknown can be measured. The known standard is simply prepared by saturating gas at a high pressure and expanding it to the extent desired. The quantity of water per unit volume before expansion is known from the vapor pressure of water, and the corresponding quantity after expansion is easily computed. An independent calibration is made in connection with each reading. Simple but special electrical measuring equipment was developed for the purpose.

Instruments and Instrumentation

Flight Test Instruments

Projects in this field were supported by the Bureau of Aeronautics, Navy Department and were carried out in close cooperation with the Flight Test Section of that Bureau. The projects involved design, construction or testing, depending upon the status of the individual development at the time the Bureau of Aeronautics submitted the problem. Representative of this phase of work were the testing of recording potentiometers, barographs, and airspeed indicators and the design and construction of suspended head airspeed indicators, pitot static heads, accelerometers, control force indicators, and ammeters.

Aerological Instruments

Radiosondes. Beginning late in 1943, apparatus and procedures were developed for testing production samples and experimental models of radiosondes for the Bureau of Ships, Navy Department. This work was done in the Aeronautical Instruments Section, under W. G. Brombacher. Laboratory tests were made on the pressure and temperature elements in
which the pressure and temperature were both decreased at specified rates. Pressure measurements were made with the aid of an aneroid barometer of good quality, calibrated at the specified rates of pressure change. The radiosonde signal was received on a service type receiver and the output of the frequency meter recorded on a Speedomax recorder.

Testing of Humidity Elements. No satisfactory apparatus is available for testing the humidity elements of radiosondes at temperatures below 0°C. At the request of the Bureau of Ships an apparatus for this purpose is under development. A stream of dry air is divided into known proportions by orifices, and one part is humidified by flowing over ice. The two components are reunited in the test chamber in which the humidity element is installed.

Barographs and Aerographs. For the Maritime Commission 144 barographs for measuring atmospheric pressure on shipboard were given acceptance tests.

Aerographs mounted on airplanes are used to obtain aerological data when radiosondes cannot be used; 147 were tested for the Bureau of Aeronautics, Navy Department. An apparatus for controlling pressure, temperature and humidity was given acceptance tests.

Standby Compass. In 1943, a standby or pocket compass was designed and constructed as suggested by Comdr. L. Wolfe of the Bureau of Aeronautics (Instrument Branch), Navy Department. In this compass, 1 3/4 inches in diameter, eddy-current damping is employed instead of the liquid damping customarily used. The compass was produced in quantity by several manufacturers for the armed services. The NBS assisted in perfecting the design and in testing pre-production models.

Superheat Meters. Superheat meters are differential thermometers, conventionally of the unbalanced Wheatstone bridge type, used in airships to indicate the difference between the free-air and lift-gas temperatures. Twenty superheat meters of NBS design were constructed for the Bureau of Aeronautics (Instrument Branch), Navy Department, and starting in 1942 the superheat meters were made commercially.

Dynamic Performance of Altimeters. Satisfactory information on the drift and errors of aneroid altimeters when the pressure is changing was unavailable at the start of the war and was needed for military purposes. This was undertaken with the financial assistance of the NACA. Apparatus was successfully developed for measuring air pressures and altimeter indications while the pressure was changing during simulated dives and climbs and the desired data were obtained.

Barometers. The standard mercurial barometer, used to test portable mercurial barometers, aneroid barometers and aneroid altimeters, was further developed. In its present state it is mounted in a constant temperature room and consists essentially of a C.392 U-tube, 20 mm in bore, a standardized stainless steel scale graduated from 0 to 800 mm in 0.5 mm intervals, and a rigid cathetometer designed and constructed for the purpose. Means are provided for measuring any residual pressure above the mercury column.

From 1941 to 1946, inclusive, 329 mercurial barometers, principally of the altitude type used by the Army and Navy for calibrating altimeters, and 192 precision aneroid barometers and surveying altimeters were tested for the U. S. Army, Navy, and various government departments.

Instruments Lubricants. Approximately 160 experimental lubricants and greases for instruments were tested for corrosion resistance, oxidation, spreading, evaporation, pour point, viscosity, and life in jewel bearings. The bulk of this work was done for the Bureau of Aeronautics (Instrument Branch), as a part of a lubricant development program in which the Naval Research Laboratory and Mellon Institute participated by producing synthetic lubricants, both spreading and non-spreading. Efforts were also made to determine the life of lubricants in ball bearings under extreme conditions of high humidity and temperature. Although the perfect lubricant for use over extremes of temperature and humidity encountered in aircraft is not yet available, progress toward the goal is being made.
Jewel Bearings

A remarkable development during the war was the wide use of glass vee bearings in instruments as a substitute for sapphire. At the request of the Bureau of Aeronautics, studies were made by the NBS of the performance of bearings made of various glasses, sapphire and spinel and also of combinations of pivots and bearings of various materials.

The resistance to shock of various assemblies of bearings and pivots was measured and the effect of vibration with its resultant wear was studied.

The difference in hardness with respect to the crystallographic axes of the bearing materials was measured by means of the diamond indenter developed by Knoop at the Bureau some years previously. Studies were also made of the hardness of the various pivots using the same instrument. Jewel bearings of various types, artificial and natural corundum (sapphire), spinel and glass were examined microscopically and tested with X-ray diffraction by the Petrographic laboratory to determine how physical properties and structural imperfections in the bearing material and surface imperfections in the finished jewel might affect the permanence of the jewel. For example, photomicrographs of the metal instrument pivots after service or after vibration tests show how the hardness of the bearing material affects the degree of deformation of the pivot and this evidence aided in demonstrating that glass bearings might efficiently be substituted for the corundum bearings which at one time were critically scarce. Again, differential wear in jewel bearings was apparently related to the crystallographic orientation of the bearings in the mounting.

Studies of differences in hardness by the diamond indenter test in different directions correlated well with the crystallographic orientation determined by X-ray diffraction. Studies of the artificially produced gem material, corundum (sapphire and ruby), and spinel developed some interesting relations of crystal axes to the axis of the "boule" which were helpful in the technology of manufacturing the raw materials and indicated economies in the fabrication of the bearing.

Microscopic examination of the bearing surfaces of crystalline and glass bearings showed how defects in the mechanically finished crystal surfaces and the fire polished glass surfaces led to inaccuracies in the finished instrument.

In all 24 joint reports were issued, copies of which were furnished specific instrument manufacturers. The Bureau helped to establish the fact that alumina glass bearings were superior in performance to bearings of other glasses, and that in general glass bearings resisted vibration better than sapphire bearings when steel pivots were used.

NBS Carbon Monoxide Indicator

During 1941, the Royal Aircraft Establishment, Farnborough, England, developed an indicator for the detection and estimation of small amounts of carbon monoxide on board aircraft. This indicator was a silica gel impregnated with ammonium molybdate, sulfuric acid, and palladium chloride. A yellow silico-molybdate complex was thus formed, and the palladium served to catalyze its reduction by carbon monoxide. This reduction occurred only when the gel contained an optimum amount of water. Since the gel lost its sensitivity with passage of air samples containing either more or less water vapor than corresponded to this equilibrium, its general field use was not practicable. The colors developed were too muddy to permit good colorimetric differentiation, and accordingly the length of discoloration in a column of gel was used to measure the concentration of carbon monoxide. This measurement was not sufficiently accurate for acceptance tests of aircraft.

In November 1941, the Bureau of Aeronautics, Navy Department, (and later the Army Air Forces) requested that the NBS study the RAE gel, with the object of improving it or developing a suitable substitute. The project was put under the leadership of Martin Shepherd. The relatively high sensitivity of the RAE gel suggested further investigation in this direction. Since it was entirely practicable to dry small air samples in the field, the first hope was to make an indicating gel sufficiently sensitive in the dry state.
When dry air was passed through the yellow RAE gel it turned a deep brownish buff and became insensitive to carbon monoxide. After investigation it was found that when a solution of a sulfate, together with ammonium molybdate, was added to a highly purified silica gel, the product was an indicating gel which was extremely sensitive to small amounts of carbon monoxide when nearly dry. Thoroughly dried air, passed for hours through this gel, did not materially alter its sensitivity. When air containing a varying concentration of carbon monoxide was passed through a column of the gel of fixed diameter at a constant rate, a series of easily differentiated, clear green to bluish-green colors were obtained which were easily matched with standards. The gel was capable of detecting and determining less than one part of carbon monoxide in 500 million parts of air; of detecting as little as 0.001 percent by volume in less than one minute; of determining physiologically significant amounts of carbon monoxide (0.01 to 0.4 percent) in about one minute at ground level; and of detecting and estimating concentrations of 0.0026 to 0.06 percent on board aircraft in one to five minutes, depending on altitude and concentration. The color response was a function of time and of concentration of carbon monoxide (since the rate of passing the air was constant); a direct parallel to the physiological response to this gas.

NBS indicating gel was first produced in December, 1941, and adapted for field use as NBS indicating tubes early in 1942. During 1942 and 1943 the optimum formula of the indicating gel and the optimum equilibrium in the indicating tube were experimentally determined. Production of both gel and tubes was greatly expanded, with necessary revision of experimental procedures. Methods for using the gel and tubes in the field and laboratory were developed. Field and laboratory instruments for using the tubes were designed and models were constructed and put into use. A machine for making and sealing the tubes was developed. Altogether, more than half a million tubes were made at the NBS for the military services of the United States, Canada, and Great Britain.

The tubes were used in the field to determine carbon monoxide in and around aircraft, hangars, carriers, tanks, gun turrets, flame throwers, garages, and other military equipment and installations. They were used in many laboratories for the accurate determination of small amounts of carbon monoxide in connection with various military investigations. One of the novel uses was the very rapid determination of carbon monoxide in the blood of persons who had been exposed to the gas. This was done without taking a blood sample from the subject. He was required only to exhale alveolar air into a 20 cc syringe, from whence the expired air was drawn through an NBS indicating tube for analysis.

Of the instruments developed, a very simple field kit proved the most popular. The sample was drawn through the indicating tube by an ordinary 2-oz rubber aspirator bulb equipped with a special rate-controlling valve. A spot test could be made in one minute; and such tests could be entrusted to untrained personnel.

The NBS indicating gel has a wide prospective peacetime application, since it provides a simple, rapid, and inexpensive means for the determination of carbon monoxide in the air and for the diagnosis of carbon monoxide poisoning. In either application it can detect and estimate any quantity of physiological significance. The tubes can be modified to serve as detectors of other reducing gases and vapors, including almost all organic vapors.
9. Fuels and Lubricants

To aid the military agencies in their development of military aviation fuels, extensive work under the leadership of F. D. Rossini was done on the detailed analysis of the components of such fuels. The individual constituents in alkylates, hydrocodimers, naphthas, and other components were determined by means of high-efficiency high-reflux-ratio distillations, supplemented by measurements of physical properties. Reports of analyses of 42 samples were submitted to the Petroleum Industry War Council, NACA, and the Army Air Forces. The information gained in this work was correlated by automotive investigators with engine performance, and by the producers of the materials with the conditions of manufacture.

Further information of value in calculations dealing with the control of manufacturing processes was gained by determining the heats of combustion of some of the hydrocarbon components of the fuels.

For many of the hydrocarbons all available data, both published and unpublished, were collected, analyzed, and correlated to yield the most reliable values of the properties of the hydrocarbons significant to their use in aviation fuels. This included collecting infra-red and ultraviolet spectograms from contributing laboratories and arranging them in a uniform manner for reproduction and distribution. These spectromgrams served to provide bases for the analysis of mixtures of hydrocarbons in the laboratories of the petroleum industry.

Engine Determination of Fuel Quality

Routine work in this field consisted chiefly of knock ratings of motor and aviation fuels, and of cetane ratings of Diesel fuels. While these were largely supply-acceptance samples, a number of samples taken from the fuel systems of aircraft involved in crashes, or forced landings in consequence of engine failure, were also tested.

The research work on this subject under the leadership of D. B. Brooks has been directed chiefly toward the development of test methods. This phase of the work was accelerated rather than initiated by the war.

Since the development of standardized engine test methods for the determination of fuel quality, the NBS has served as the agency for the calibration of primary reference fuels, which is based on the measurement of certain physical properties of these fuels. In 1936, the automotive section prepared highly purified samples of normal heptane and isoctane and made accurate determinations of the physical properties of these compounds. Several years earlier a study had been made of the impurities present in these two primary standards. The result of this work was to establish the amount of impurity which could be tolerated in the primary reference fuels without detriment to their use in knock rating. On the basis of this work, specifications for these materials were prepared and submitted to the American Society for Testing Materials and adopted by that organization. All normal heptane and isoctane used in engine work since has been prepared in accordance with these specifications. A sample of each batch of these reference fuels is submitted to the Bureau where precise determinations are made of the boiling point, freezing point, refractive index, density, and knock rating. Acceptance of the sample is based on the results of these tests, no other laboratory being involved in this calibration.

Owing to the high cost of the primary reference fuels, secondary reference fuels are commonly used in engine ratings of samples. These are prepared by designated oil companies and cooperative tests are then made comparing the secondary fuels with the primary fuels. From these results the calibration of the secondary fuels is established. The same procedure is used in the case of so-called standardization fuels which are used for the purpose of ascertaining whether the test engine is in proper condition for making ratings.

During the war a large number of companies were making aviation fuel. Many of these companies had no previous experience
in the engine determination of anti-knock quality of such fuels. To minimize the errors resulting from this lack of experience, the military air services set up so-called referee fuels, the compositions of which closely approximated average aviation fuel production in each grade. The knock ratings of these fuels were determined accurately by cooperative tests and the fuels were then adjusted to have the minimum acceptable knock rating for the grade in question. The Bureau participated actively in this cooperative work and also furnished special data that could not be obtained by other laboratories.

The NBS has participated actively in the improvement of test methods in two respects. The Bureau has cooperated with industrial laboratories in the rating of Exchange samples (by motor, aviation, and Diesel test methods) each month, and has served as the agency directing the operation of Exchange groups in each of these fields, and has analyzed the resulting test data. In each of the fields of Diesel, motor, and aviation fuel rating an Exchange group comprising 20 to 35 laboratories, chiefly those of industrial concerns, is operated. Each month one of these laboratories furnishes samples to all members. Tests are made on a specified day of the month and the results are reported to the NBS. These results are analyzed and a report giving pertinent information is issued. Twice each year all laboratories possessing adequate equipment are invited to participate in the rating of samples. The results of these semi-annual tests are likewise analyzed by the Bureau and reports issued to all participants.

Owing to the comparative inexperience of many industrial organizations called upon to produce aviation fuel during the war, the military air services urged that steps be taken toward improving the precision of testing by these laboratories. Arrangements accordingly were made for all such laboratories to participate monthly as nonmembers in the aviation Exchange group. This action greatly increased the work required to operate the Exchange group and to analyze the test results. At the peak, just before V-J Day, 55 laboratories were participating as non-members in addition to 36 members.

Besides reports on the monthly and semi-annual Exchange tests the Bureau has periodically prepared an exhaustive analysis of cooperative test data accumulated during 3-year periods. Such analyses were published in 1938, 1939, and 1942. Early in 1945, these triennial analyses were compiled and were distributed to a restricted list of organizations. The analysis of the aviation fuel data showed that the precision of both the cruising and rich mixture take-off ratings was about 2 performance numbers. A detailed study of the results showed that when procurement of fuels was to be based upon a single acceptance rating the specification must be set 6 performance numbers above the minimum acceptance value to assure fuel of the desired quality.

This figure occasioned considerable surprise on the part of the military air services and was questioned by them. In order to determine whether or not some factor might have entered into the data, upon which the above figure was based, other than those normally prevailing in routine rating, a series of six special samples, known as precision samples, were distributed to every owner of aviation fuel test engines in the United States and Canada. The recipients were requested to rate the samples, sufficient for only one test, in the same manner as they would make routine ratings, and to report the data. Over 85 percent of those to whom samples were sent reported the data as requested. The results of these tests fully substantiated the conclusions reached in the triennial report and convinced the air services that their belief in a higher degree of precision was unfounded.

**Knock Ratings at Altitude**

Some years ago it was noted that knock ratings of motor gasolines when made by laboratories located at considerable elevations above sea level did not agree with ratings of the same gasolines made by laboratories operating at sea level. As early as 1937, a
cooperative investigation was made which clearly showed the effect of altitude upon ratings. As a result of this investigation, certain changes in method were prescribed for use at different altitudes. Some improvement followed, but the agreement still was not satisfactory. Early in 1941, the Bureau was asked by the CFR Motor Fuels Division to assist in determining appropriate conditions for knock rating by the ASTM motor and CFR research methods at altitudes up to 7,000 feet. A series of cooperative tests was carried on in one of the Bureau's altitude chambers, skilled technicians and additional test engines being made available by the participating organizations. As a result of this work, a new test procedure was promulgated and after being subjected to field tests was adopted. This work made it possible for laboratories at altitudes up to 10,000 feet to obtain results in agreement with those found by laboratories operating at sea level.

Extension of Octane Number

The octane number scale developed in 1930 for use in conjunction with the rating of motor fuels formed the basis also for rating aviation fuels. As long as these fuels were not better than isoctane this scale was entirely satisfactory. Nearly a decade ago, however, the quality of aviation fuels had been improved to the point where some of them equalled isoctane in knock rating. As such fuels are a mixture of several components it followed that some of the components were superior to isoctane. Ratings of these components were made in terms of the amount of tetraethyl lead which must be added to isoctane to make the latter equal the component in knock rating. This extension of the octane number scale was satisfactory for some years but with the advent of aviation fuels of even higher octane number the limit of this scale was finally reached, for the addition of tetraethyl lead to isoctane had little effect in improving the knock rating of the latter and caused erratic engine operation. The CFR Aviation Fuels Division, therefore, appointed a special committee to study the extension of the knock rating scale, with the NBS representative as the chairman of the committee.

This committee has carried out an extensive program of exploratory research on reference fuel scales and on systems for expressing knock rating in terms that would be of maximum usefulness. The Bureau's engine laboratory has been the largest contributor in this cooperative research. While the work is not yet completed present indications are that it will result in a so-called "triptane number" scale, useful in fuel blending work, and in a "Detonation Index" which will express the results of knock ratings in the form most useful to engine manufacturers.

Aviation Fuels

In the investigation of the impurities present in primary standard reference fuels used in knock rating about 20 paraffin hydrocarbons were isolated as impurities in certified isoctane. A few of these compounds had knock ratings higher than isoctane, which suggested the desirability of an investigation to determine what types of compounds had knock ratings higher than isoctane.

A research program was prepared in the spring of 1936, and discussed with representatives of the Army Air Corps, the Navy Bureau of Aeronautics, and the National Advisory Committee for Aeronautics. By the following year the support of these agencies had been obtained and the project was initiated on July 1, 1937. Its stated objective was the synthesis of an aviation fuel meeting the current specifications with respect to volatility and having a knock rating above that of isoctane when used without the addition of tetraethyl lead.

The early days of this investigation were characterized by a continual struggle to develop equipment, to obtain personnel of the requisite training, and to maintain the interest of the sponsors until results of
value could be had. One of the first needs of the work were fractionating columns of higher efficiency and throughput than had been built at that time. The columns which were designed at the NBS for this work were approximately twice the size of the largest laboratory equipment then in use and were essentially automatic in operation. This required the development of a number of untried gadgets of novel design. Late one Saturday evening after an arduous day spent connecting the last of the dozens of electric circuits required, the automatic features of the columns were given their first trial. All equipment functioned as intended and the columns operated without shut-down for many months except when interrupted by a failure of the power supply.

Synthetic hydrocarbon preparations soon began to issue from this laboratory in increasing volume. When this work was started only a very few triply-branched paraffins and one paraffin having four branches had ever been made. The hydrocarbon research laboratory has now prepared many hydrocarbons having 3 or 4 branches and 4 hydrocarbons having 5 branches. To date, 78 hydrocarbons have been prepared and of these, at least 66 were prepared in higher purity than ever before. Of these compounds, 21 had never been claimed to have been made before. In several other instances the compound described in the literature had properties so different from those found for our high-purity preparations as to make it exceedingly unlikely that the alluded preparation was actually the hydrocarbon claimed.

In addition to the hydrocarbons which have been synthesized, a considerable number have been prepared by fractionation of alkylates, polymers, and other mixtures which might be called synthetic crudes. Fractionating columns of ever greater capacity and efficiency have been required. When this work began, fractionating columns having a four-liter pot and an eight-foot column were considered the last word. The latest columns constructed have pots of one barrel capacity and columns of 55 feet in effective height, the overall dimension being about 64 feet.

Toward the close of the war, these columns were called upon for a purpose unforeseen at the time of their construction. At the request of the Petroleum Administration for War, a representative thermally-reformed naphtha was carefully fractionated into its components. These components were subjected to knock rating by the current aviation fuel test methods. The purpose of this work was to ascertain whether portions of these naphthas could be withdrawn advantageously by super-fractionation to augment the supply of aviation gasoline. It was found in the case in question that material which could be removed by super-fractionation over at least two temperature ranges would be a desirable addition to aviation blending stock. The interest aroused by this work was such that the NACA has asked the Bureau to analyze one commercial naphtha each year in this manner so that a method and technique will be immediately available in the event of any future emergency.

The NACA has also requested that the hydrocarbon research program be carried beyond the volatility range of present aviation fuels and into the range of what are erroneously called safety fuels. Samples of the highly purified compounds produced in this laboratory are not only subjected to knock-rating tests but are also furnished to laboratories cooperating with American Petroleum Institute projects for the determination of physical properties, including infrared spectrum analysis. Thus the project which began as a study of the impurities in one hydrocarbon has now become one of the largest sources of pure hydrocarbons. Following the lead of this project the American Petroleum Institute later initiated a similar project of its own. Several years later the NACA also established its own laboratory to work on the synthesis of hydrocarbons. Through constant interchange of information, the work of these two projects has been coordinated with that of the original National Bureau of Standards project so that no overlapping occurs.
FUELS AND LUBRICANTS

Heats of Combustion of Aviation Gasolines

Specification AN-F-28 for aviation gasolines contains a minimum requirement for heat of combustion. Measurements on 57 gasolines were reported in NACA Technical Note No. 996, entitled Net Heat of Combustion of AN-F-28 Aviation Gasolines. This report pointed out a close relationship between the heat of combustion and the aniline point. Most laboratories are not equipped to measure heat of combustion with adequate accuracy. Determinations of the aniline point however are relatively simple. Largely on the basis of this work, Amendment 3 was added to the specification which supplied the manufacturers with an easy means of checking their product to meet this part of the specification.

C₄ Liquid Hydrocarbons

A statement frequently heard is that "we won the war with C₄ hydrocarbons." The basis for this statement is that these hydrocarbons were the major source material for high quality aviation gasoline and for synthetic rubber. NBS LC756, giving the liquid densities of eleven hydrocarbons found in commercial C₄ mixtures and NBS LC757 dealing with volume correction factors for C₄ hydrocarbon mixtures, contain extensive tables which have been accepted and used in calculations of quantities of these liquids bought and sold in the industries processing C₄ hydrocarbons.

Heats of Vaporization

High precision measurements have been made of the heat of Vaporization of 60 pure hydrocarbons ranging from C₄ to C₁₀ which are of importance in the development of adequate supplies of high quality aviation gasoline. In addition, heat capacity measurements were made on some of these hydrocarbons. The apparatus was especially adapted to the use of the small samples of material which were available with some of the pure hydrocarbons. The results of this work have been included in the extensivetables distributed under API Project 44.

Motor Fuels

Early in 1942, it became difficult to supply some friendly countries with motor gasoline for the transport of critically needed materials to seaports, because of the loss of our oil tankers by enemy action. A possible alternative was the local production of substitute fuels from vegetable matter. The Foreign Economic Administration asked the National Bureau of Standards to investigate fully the engine performance of substitute motor fuels, of which alcohol was the most promising. The resulting investigation also included charcoal, shale oil, naphtha, vegetable products, and certain fuel gases. For the liquid fuels, the work covered studies of the volatility of the fuels and blends, rates of evaporation loss, effect on pump diaphragms, starting, warm-up, vapor lock, manifold distribution, knock rating, power, economy, spark advance, oil consumption and dilution, engine deposits, cylinder wear, and exhaust composition.

Extensive tests of cylinder wear were carried out in the course of this investigation. The wear was measured by the wear gage developed by S. A. McKee of the Bureau staff. By means of this instrument a diamond-shaped pyramidal indentation is made in the cylinder wall. As the cylinder wears, the length of the indentation decreases, and measurements of the length of the indentation can be translated into highly accurate determinations of wear. This method of measuring wear has the following advantages: (1) Only actual wear is recorded; (2) the high precision—one-hundred-thousandth of an inch wear is detectable—shortens the duration of the test and makes it possible to obtain comparative wear determinations before any gross change in engine condition has occurred.

It was found that the wear when substitute fuels were used was less than for gasoline. It was also found, as has been reported by many investigators, that the wear increased rapidly at lower temperatures.
This effect, which was quite pronounced at temperatures below 60°F, was presumably caused by accelerated corrosion.

A series of tests was also made on an engine equipped to operate on either gasoline or producer gas from charcoal. At an average load it was found that one gallon of gasoline could be replaced by approximately 11 pounds of charcoal. The servicing of the gas generator constitutes the greatest drawback to the use of charcoal as an automotive fuel. The filters used to clean the gas require frequent attention even with the best grade of charcoal obtainable. Starting usually required about two minutes and with proper technique was not a problem. The conclusion was, however, that operation on any liquid fuel would be preferable to operation on charcoal.

The general conclusion from this research was that operation on substitute fuels such as alcohol, or acetone and butanol, is feasible and should not increase maintenance. Such fuels can be adapted to a considerable range of climatic conditions by use of appropriate blending agents. Maximum power may exceed that with gasoline by a few percent. Fuel mileage was found to be approximately proportional to the heat of combustion of the fuel. However, engines especially designed to exploit the high anti-knock properties of substitute fuels would reduce the difference in mileage.

Alcohol as a Substitute Fuel

In March 1944, the Army requested information as to the feasibility of operating automotive engines on low-proof alcohols. Test runs were accordingly made on alcohols of various proofs with standard spark plugs. There was some difficulty when operating on low-proof alcohol because of wetting of the spark plugs, but when a special type of hot plug was installed it was possible to operate on an alcohol as low as 70-proof, which contains nearly 75% of water (by weight). However, there were certain difficulties which indicated that engine operation on alcohol of very low proof was impractical. There is considerable loss of power and efficiency, redesign of the fuel system is necessary, and excessive volumes of fuel are required. For example, a vehicle which could operate 200 miles on a tank full of gasoline could go 130 miles with absolute alcohol, but could only go 25 miles on a tank of 70-proof alcohol. It was accordingly recommended to the Army that power alcohol should be distilled to the highest possible proof before using.

Gasoline Additives

Because of the shortage of gasoline during the war an unusual number of gasoline additives were marketed with the usual claims of greatly increased mileage, improved power and generally better performance. Many examinations were made and reported to the agencies requesting the tests, including the Post Office, Federal Trade Commission, and the War and Navy Departments. With one exception the additives tested were found to be of no value whatever, as has been our uniform experience with such materials over many years. The one exception was an additive containing iron pentacarbonyl. This material is similar to tetraethyl lead in its effect on knock. However, it has been found to greatly increase engine wear.

Gasoline-Water Separators

Early in the war the U. S. Engineer Corps sent to the NBS a number of devices designed to remove water from a flowing stream of gasoline. Several airplanes had been lost under mysterious circumstances, and it was assumed that water in the gasoline had stopped the engine. None of the devices submitted were satisfactory, for one reason or another, until Colonel Hibbert Hill sent to the Bureau, Warner Lewis, a resident of Oklahoma, with experience in the oil fields. Mr. Lewis had an idea that wood excelsior would serve as a medium for separating water from gasoline flowing in a pipeline. Designs for experimental equipment were, prepared by Lewis and H. E. Robinson of the NBS and experiments were begun, with Lewis furnishing the separators, as they came to be called. After a few months, proper flow rates had been discovered and with proper automatic controls, excelsior separators were found
effective in arresting practically all entrained water, including emulsified water in the gasoline or a "slug" of water, delivered to the separator in continuous flow, following a flow of gasoline. Suitable automatic controls were then developed and separators were built commercially, and have continued to be used on Army airfields. Later, small separators were adapted to gasoline tank trucks and this is probably their main use by the U. S. Navy.

The ability of the excelsior plugs to arrest dirt in the gasoline had been established by test at the Bureau. A typical separator now may have a capacity of 1,000 gallons of gasoline per minute with a pressure drop, through the separator, of 1.6 pounds per square inch. If the gasoline contains up to 6 percent water, the pressure drop may rise to 5 pounds per square inch, during the separating process. If a flow of all-water (or a "slug") is received, the separator, owing to its automatic controls, will stop the flow entirely. The excelsior appears to last indefinitely if the gasoline contains only water. If dirt or sludge is present, the excelsior plugs, like any other filter, require replacement.

Lubricant and Fuel Problems

Early in the war, Dr. O. C. Bridgeman of the NBS staff was detailed to Army Ordnance to assist in their work on fuel and lubricant requirements of military vehicles such as tanks, gun carriages, and trucks. During this period emphasis was placed on the simplification of the multiplicity of grades of fuels and lubricants in use at that time, in order to reduce the difficulties in supplying these commodities to the various theatres of operation. Assistance was given in drawing up specifications for this purpose, in laying out test programs to obtain further information on service requirements where necessary, in carrying out these programs, and in recommending design changes in the vehicles where indicated.

The Lubrication and Liquid Fuels Section also assisted in determining the lubricating oil requirements of tank engines by undertaking a considerable amount of analytical work on oil samples taken during engine tests and by special studies of the stability characteristics of selected lubricating oils.

Oil Filters

During the war period, the NBS expanded its work on automotive oil filters to include the effect of these filters when operated on additive lubricating oils used by the U. S. Army for heavy duty operation in military vehicles. Measurements were made of the efficiencies of all military standard oil filters and of the tendency of these filters to remove the additives from the oils. On the basis of this work, the U. S. Army specification for oil filters was revised and all filters purchased by the Army were required to pass the efficiency tests developed at the Bureau for operation on both additive and non-additive oils. The specification also included the method developed for the determination of the amount of the additive removed by oil filters.

Vapor Lock

The National Bureau of Standards, in cooperation with the Coordinating Fuel Research Committee, continued its work on phases of the aviation vapor-lock problem that would assist the military services in preventing vapor lock in aircraft fuel systems. The investigations furnished basic information on the properties of aviation fuels related to vapor lock, with particular emphasis on vapor pressure, viscosity and gravity characteristics. In addition, surveys were made periodically for the military services of the properties of commercial aviation gasolines supplied under the major Army-Navy Aeronautical specifications for this type of fuel.

In several cases of failures in military aircraft due to vapor lock, the NBS assisted in the analysis of the causes of the difficulties and in their elimination by application of information on fuel characteristics and on fuel-system design.
Starting of Aircraft Engines at Low Temperatures

One method used by the Army Air Forces to facilitate the starting of an airplane engine in cold weather was to inject gasoline into the lubricating system after the plane had returned from its mission and the engine was still warm. This dilution of the lubricating oil lowered its viscosity and made it easier to crank the engine after it had cooled. After starting, this gasoline was evaporated by the heat from the engine, leaving the oil undiluted again.

In the fall of 1942, under conditions of extreme urgency, the AAF asked the Bureau to undertake a comparison of the AAF method with another method for injecting gasoline into the lubricating system. The two methods had the same object but differed as to the point in the lubricating system where the injection was effected. This work was immediately undertaken and a complete lubrication system for a P-40 fighter plane was set up with the engine simulated by a heat interchanger consisting of a steel tank in which the lubricating oil was sprayed over steam coils to obtain the exchange of heat. Various tests were made controlling the temperatures and rates of oil flow to simulate field conditions. Samples of oil were taken from different points in the system and examined for viscosity and dilution to give a picture of the condition of the oil throughout. These tests were run using each method of injection and gave a satisfactory comparison of the merits of the two systems.

High Viscosity-Index Oils

During the summer of 1940, work was started, in cooperation with the Bureau of Aeronautics, Navy Department, on the study and development of high viscosity-index lubricating oils in order to provide oils which remain fluid at very low temperatures and have sufficiently high viscosity at high temperatures. Such oils would permit the elimination of a number of viscosity grades while still providing oils suitable for starting under low-temperature conditions and for maintaining satisfactory lubrication at high engine temperatures. Two types of oils were studied: Hydraulic oils for use in aircraft control systems; and aircraft engine lubricating oils. New viscosity-index improvers were submitted that were better than any previously employed. The type that was found most satisfactory was later used in hydraulic fluids for Army and Navy aircraft, after further work by the Pennsylvania State College.

Testing of Lubricants and Fuels

An NBS unit was engaged in the testing and analysis of fuels and lubricants used by the armed services and other Government agencies, and it assisted in the development of aviation gasolines and jet propulsion fuels. Assistance was given in the development of specifications for leather dressings, ski waxes, propeller-hub packing compounds (for ships of the U. S. Maritime Commission), in the analysis of a few captured enemy fuels and lubricants, and in the substitute fuel program. This group also supplied oils of known viscosity for use in the calibration of viscometers in laboratories of war plants and the armed services. There has been a steady increase in the demand for these standardized oils since 1939, but the average annual demand more than doubled during the war years.

Oil in Steam Condensate

At the height of the submarine campaign the lack of sufficient facilities for the manufacture of Diesel and steam-turbine engines threatened seriously to curtail the shipping of supplies overseas. It was decided to fall back on the old style reciprocating engine that could be produced in quantity. The major objection to the use of this type of engine was that the steam condensate contained upwards of 50 parts of emulsified oil per million parts of water. The condensate could not be reused in the boiler because the oil would decompose, cause fouling of the boiler tubes, and eventually cause failure of the boiler under load. This type of engine had previously been limited to use in installations to which fresh water could be continuously supplied.
The Bureau was requested by the U. S. Maritime Commission and the Navy Bureau of Ships to assist (1) in determining the oil content of the steam condensate under varying conditions of service, (2) in devising methods suitable for use on shipboard which would remove the emulsified oil to a limit of 0.1 part per million, and (3) in developing instruments and procedures for the determination of the oil content of the condensate on shipboard. The NBS Project leader was S. F. Acree.

At first, chemical methods were used for the determination of the oil content. Later, the oil content was determined by measuring the turbidity of the condensate, especially when the content was low, as in the case of condensate already treated to remove oil. To adapt the turbidimetric procedures for use on board ship, a special turbidimeter had to be developed. The instrument which was designed is a rugged, portable one, capable of determining the oil content of the condensate to 0.05 part per million. It consists essentially of two photo-cells which compare the light transmission of air and of a sample of the condensate. A photo-cell indicator serves to detect the balance point.

For standardization of the instrument three types of turbidimetric standards were devised. One of these was a suspension of finely divided carbon in a suitable liquid medium, another consisted of films of gelatin in which colloidal carbon was dispersed, and the third consisted of glass blocks polished to give graded light transmissions as suggested by D. B. Judd.

Tests of filter systems which had been submitted to the Bureau of Ships for use in treating the condensate to remove oil showed that the oil condensate in general was not brought below 10 parts per million, which was approximately 100 times the acceptable limit. Laboratory tests of emulsified oil indicated that, to improve this, fundamental studies were needed regarding the following points: The electrical charges and the cataphoretic mobility of the oil particles and the materials proposed as filter media; ultramicroscopic (visual and photographic) studies of the size and distribution of the particles of oil, chemicals, filter aids, and filtered sludge; the efficiency of adsorptive and chemical flocculating agents in filters at various temperatures and rates of flow, to secure optimum working conditions; and the analysis of treated and untreated waters for pH, conductivity, dissolved and suspended solids, and oil content.

From the results of these investigations, a very simple adsorptive process was developed in which (1) the negative charge on the oil droplets was neutralized by means of the positive charge on a solid filter specially selected for its insolubility and chemical inertness toward the boiler water; (2) the colloidal particles of oil were coagulated into comparatively large globules by virtue of the removal of their charge; (3) the coagulated oil was removed by a filter of diatomaceous earth; and (4) the accumulated oil was periodically withdrawn through a valve at the top of the filter chamber. The oil content of the treated water varied from about 0.01 ppm when the filter bed was fresh to the permitted limit of 0.1 ppm when the bed approached exhaustion. The exhausted filter could be replaced readily with fresh material. The process for treating the condensate was used on fifty escort carriers and on a considerable number of Liberty ships.
10. Mechanics, Structural Engineering, Hydraulics

Many of the projects in mechanics are discussed elsewhere in this volume—the work relating to guided missiles and aerodynamics, for example. Numerous other projects in mechanics, sound, structural engineering, and hydraulics constituted part of the war work of the NBS, such as the properties of thin sheet, stress analyses, strain gages, concrete, hydraulic model tests, and special sound problems.

Wire Strain-Gages
Performance Tests

The resistance-wire strain-gage consists of a few inches of wire, about 0.001 inch in diameter, bonded to a piece of thin paper. The gage is attached to the structure to be tested with a suitable cement. It is allowed to dry and is then connected into a Wheatstone bridge which is, in turn, connected to a strain indicator or recorder. As the structure is strained the wire gage is strained along with it. Its resistance changes in proportion to the average strain along the wire and this change in resistance is given by the indicator or recorder. A temperature compensating gage is usually connected into the bridge to compensate for variations in resistance caused by temperature changes rather than strain.

The wire strain-gage provides a simple, cheap, and practically inertia-less means of measuring or recording strains at any point on a structure to which a gage can be attached. Because of these outstanding advantages the use of wire strain-gages has spread throughout the aircraft industry during the war years, and it attained a volume of well over one-half million gages per year.

Because of the widespread use of wire strain-gages the National Advisory Committee for Aeronautics requested the Bureau to make performance tests of wire strain-gages of types used in large quantities by the aircraft industry. The purpose of the performance tests was to determine which types of gages showed the best performance and to obtain an estimate of the accuracy with which strains could be measured with the gages under various conditions of use.

A test procedure was worked out in cooperation with the NACA and the leading makers and users of wire strain-gages and a sensitive ratio set, for accurately measuring changes in resistance, was built following a design by F. Wenner.

Tests were made by W. R. Campbell on 15 types of gages to determine calibration factors in tension and in compression, change in resistance when the wire was strained in tension beyond the elastic range, and sensitivity to transverse strains. Tests were also made to determine the errors which may be present when wire strain gages are used to measure strain at the surface of thin sheet, and errors introduced by temperature changes.

The results of the first three phases of the test program were described in NACA Technical Notes, 954, 976, 979. These technical notes have received wide circulation and have been useful in indicating the order of accuracy that may be expected with various types of gages and in showing that it is sometimes possible to increase the accuracy by prestraining the gages. The tests on transverse effect suggested a method of constructing gages with zero transverse sensitivity, which is to be tried out in the near future.

Applications

The experience of the Engineering Mechanics section in using and testing wire strain gages of many types has been utilized in a number of applications to the measurement of mechanical quantities other than strain. The applications include the following:

1. Construction of a tension dynamometer of 15,000 lb capacity for measuring the force applied by a cable or tension member to a test specimen. This was used in proof tests of a bomb cradle.

2. Construction of a small and rigid compression dynamometer of 160 lb capacity to determine the compression force exerted by an indentation hardness testing machine.
3. Determination of residual stresses in castings. The residual stresses are determined by attaching wire strain gages to the casting and then measuring the change in strain as the metal is removed around the gage. The technique has been useful in indicating the magnitude of built-in stresses in magnesium alloy castings that had cracked in service on naval aircraft.

4. Measurement of small vibrational displacements. A "ring" gage was built which proved useful in measuring the vibration present in a wind tunnel under construction at the NBS.

5. Measurement of dynamic pressure. A pressure pick-up with a capacity of 300 lb/in² was built for measuring the rapidly varying pressure in the oil chamber of a model alighting gear developed for the Bureau of Aeronautics, Navy Department, to study landing impact.

6. Measurement of muscular force. A device was suggested to the U.S. Public Health Service and was calibrated for them. With it one can measure the muscular force developed in gripping the device in one or two hands or in exerting forces on it with other parts of the body. The device has a pair of strain gages on an elastic plate which is the force-sensitive element. It will be used to measure the recovery of muscular vigor in convalescents from paralysis.

7. A very small pressure gage was built for the Naval Medical Research Institute to measure local pressure on the abdomen when the body is subjected to impact forces as during a crash landing.

Acceleration Pickups

The structural design of airplanes proceeds generally from specified or calculated values of accelerations to which the airplane is subjected in various critical flight conditions. Multiplying these accelerations by the masses gives the inertia forces to which the structure of the airplane is subjected, on the assumption that the airplane acts as a single rigid body. This assumption has been questioned particularly for large airplanes, which may show elastic deflections of several feet. Hence it has been found advisable to measure accelerations in flight tests and to compare the measured accelerations with those on which the design is based. The measured accelerations have been found to deviate greatly in several cases from the assumed values and furthermore the accelerations measured by different accelerometers have sometimes been in disagreement. It has become important, therefore, to develop accelerometers of several types whose indications could be checked one against the other.

The NBS has participated in the development of two types of electrical acceleration pickups, both for the Bureau of Aeronautics. The first type uses the variation in resistance of strain-sensitive wire when the length of the wire is changed by acceleration and the second uses the variation in the current in a vacuum tube when the spacing between electrodes is changed by the acceleration. The project was conducted by A.E. McPherson, W. Ramberg and L. B. Tuckerman.

Several different types of acceleration pickups using strain sensitive wire were built. The first of these, which contained a small mass supported on bare fine wire under initial tension, failed to function satisfactorily because of difficulties in anchoring the wire and maintaining it under sufficient tension. However, the idea was taken up later by the Statham Laboratories in Los Angeles, the difficulties were overcome, and a line of successful acceleration pickups was developed for commercial use.

Good results were obtained at room temperature in the laboratory with the pickup of the second type, in which the strain-sensitive wire is wound on a disk of rubber to maintain it under initial tension. A small mass is supported on the rubber disk. Acceleration of this mass deforms the disk and strains the wire. The strain is recorded as a change in resistance with any one of the many circuits developed for amplifying and recording the output of resistance wire strain gages.

The third type of pickup has been built which offers promise for measuring accelerations in ballistic work. This pickup uses the strain-sensitive wire to guide as well as support a very small mass.
Vacuum Tube Pickup

A vacuum tube pickup of advanced type was developed for the Bureau of Aeronautics with the cooperation of Sylvania Electric Products, Inc. It contains a fixed rectangular cathode with 2 plates a few thousands of an inch to either side of the cathode. The plates are mounted on elastic supports inside the tube so as to deflect under acceleration normal to the plates. This produces a change in the current from plate to cathode of sufficient magnitude to operate a recording galvanometer in a Wheatstone bridge, without requiring amplification.

About one hundred vacuum tube pickups of this design have been built. Most of these are to be distributed to aircraft companies and other agencies engaged in flight tests. The vacuum tube pickup has been used successfully at Wright Field to measure accelerations on objects that are catapulted in order to study the forces to which a pilot is subjected when he is thrown from a fast military airplane; also in drop tests of a model airplane at the NBS to study landing impact (Bureau of Aeronautics). Tubes have been provided to determine accelerations on radio transmitters (Naval Research Laboratory) and to record accelerations on bodies under impact in studies of the physiological effects of crash accelerations (Navy Medical Research Institute).

In addition to obtaining records of acceleration versus time, accelerometers of the scratch type were developed for the Bureau of Aeronautics in order to obtain records of maximum accelerations during an airplane crash. It was hoped that such records would indicate the forces acting on the pilot's seat during a crash and would make possible improvements in the design of the seat which would save the lives of more pilots in crashes during training.

The accelerometer consists of a mass mounted on a leaf spring pressed against a round button. Acceleration above a certain minimum value will lift the mass off the button. The deflection of the mass is scratched on the fixed chromium-plated target by the scriber which is attached to the mass. The length of the scratch is measured under a microscope to estimate the maximum acceleration in a given direction.

Service records of these accelerometers taken from airplanes which had experienced rough landings and mild "crashes" indicated extremely high accelerations and could not be used, therefore, to estimate the forces acting on the pilot's seat. Nevertheless, the tests fulfilled a useful purpose in indicating the presence of intense vibration and of the high local accelerations of extremely short duration, and in pointing to a new method of attack in which an attempt will be made to record maximum forces rather than maximum accelerations.

Mechanics of Materials and Structures

Compressive Properties of Thin Sheet

The development of methods for determining the compressive properties of thin sheet became necessary with the use of high-strength sheet metal as a "stressed skin" covering of airplane wings and fuselages.

If the stressed skin is too thin there is a danger that it may buckle in portions subjected to high compressive stresses. The buckling load can be estimated from the thickness of the sheet, the spacing of the stiffeners to which the sheet is fastened and the compressive stress-strain curve of the material.

Several methods are now available for determining the compressive stress-strain curve of the material, starting with the "pack method" which was developed at the NBS several years before the war. All these methods have in common the problem of supporting the thin sheet specimen against buckling under load without affecting the stress-strain curve by the restraint.

In the pack method the restraint is provided by lateral pins bearing on the two opposite sides of a "pack" of nominally identical "leaves" cut from the sheet. In the Montgomery-Templin method the specimen consists of a single leaf to which lateral support is supplied by a set of small cylindrical rollers.

In the "lubricated solid guide" method developed by C. S. Atchison at the NBS in
the first years of the war, the support is reduced to two simple solid guides with a thin film of high pressure lubricant between guides and specimen to reduce friction. With the NBS solid guide method it is possible to make precise compressive tests of thin high strength sheet metal with as much ease as a tensile test. The method has been successfully applied to determine the compressive stress-strain curve of stainless steel sheet with a thickness of only 0.008 inch with a yield strength of 160,000 lb/in.\(^2\) and that of 0.020 inch stainless steel sheet with a yield strength as high as 240,000 lb/in\(^2\).

Comparison of the stress-strain curves obtained by the above three methods shows close agreement. This has increased confidence in the results of compressive tests of thin sheet metal and has advanced their use throughout the industry in all those cases where an accurate knowledge of compressive properties is essential.

**Axial Fatigue of Sheet**

Axial fatigue tests of sheet specimens with and without stress concentrations were made for the NACA to study failure under alternating loads in high strength aluminum alloy sheet for aircraft.

The likelihood of fatigue failure under alternating loads has increased in modern aircraft with the introduction of the new high-strength alloys and with the increase in efficiency of design which loads the material more nearly up to the yield strength, leaving less margin to carry the alternating loads due to vibration from various sources. Too little is known so far of the vibratory loads on aircraft to design for them directly. Instead service experiences with the earlier aluminum alloys and frequent inspection in service are relied upon to prevent an epidemic of fatigue failures. In addition, fatigue tests in the laboratory are made to compare the fatigue strength of the new alloy with that of older alloys which have a good service record.

The NBS took part in the last phase of the work by developing methods and apparatus for testing thin sheet metal under alternating axial loads including compression and by making tests of sheet with and without definite stress concentrations.

In the past most investigators have used flexural loading for fatigue tests of sheet metals because it is difficult to stress a specimen uniformly under axial load, especially in compression. However, axial loading was adopted at the NBS because it permits testing of cladded metals. A special testing machine was constructed and floating lubricated steel guides were developed to prevent the thin sheet from buckling during the compressive portion of the loading cycle. This made possible fatigue testing under reversed load up to high stresses to produce failure after less than 1000 cycles of alternations. Comparison of the tests of specimens with and without a circular hole gave a measure of the susceptibility of the material to the stress concentration which tends to start a crack at the edge of hole. The stress concentration from a circular hole is especially suitable since it can be well controlled and can be calculated from elastic theory.

The tests of one of the new high strength aluminum alloys showed a fatigue strength that was about equal to or lower than that of the earlier aluminum alloys. Some of the new alloys showed greater susceptibility to stress concentration than the old alloys.

The fatigue tests also showed an advantage in ease of testing and greater consistency of data for tests with the known stress concentration of a circular hole as compared to the conventional fatigue specimen with the unknown stress concentrations from machining marks and surface flaws.

Tests under alternating loads with varying amplitude showed that the sequence of loads applied to the material had a decided effect. Working up from low to high amplitudes was less damaging than working down from high to low amplitudes.

A continuation of this type of fatigue testing in the laboratory together with measurements of alternating loads in service should go a long way toward providing a sounder basis for the fatigue design of aircraft structures.
Deflection of Thin Plates

An analysis of thin plates by the large deflection theory is essential for a fundamental understanding of the load carrying capacity and resistance to buckling of the metal skin of modern aircraft. The skin is relied upon to carry a large proportion of the load in flight and it is required to maintain the surface of the airplane aerodynamically "clean" to prevent excessive drag. It is essential, therefore, to know how the portion of the load carried by the sheet and the buckling load depend on the elastic properties of the skin, the skin thickness, and the type of support by longitudinal and transverse stiffeners.

An understanding of this problem can be obtained by noting that the skin is generally divided into rectangular fields by the stiffeners. Each field can be treated as a rectangular elastic plate supported along the edges and subjected to edge loads and normal loads that approximate the loads under various critical flight conditions. The analysis of such plates is complicated by the fact that the lateral deflection of the plate under load is not always small compared to the thickness and hence it is not sufficient to use the simple linear plate theory. It is necessary to solve the much more complex equations of the non-linear large deflection theory proposed by von Karman about 30 years ago.

A procedure for solving von Karman's equations in terms of trigonometric series was worked out by S. Levy and specific solutions obtained. They have been checked by test results in all those cases where the conditions of the test approximated those assumed in the analysis.

The theoretical results have been of importance in bringing out the surprisingly small effect of the condition of support along the edges of the plate on the load carried by the sheet and on the buckling load, and in explaining the interrelated effects of curvature and of lateral pressure. Practical use of the latter has been made recently in the design of integral fuel tanks for a fighter airplane.

High Strength Sheet

The war years witnessed a remarkable development of high-strength lightweight alloys for aircraft. Aluminum alloys are now available with yield strengths and tensile strengths nearly twice as large as those for aluminum alloys in common use on aircraft ten years ago.

With the introduction of each new alloy it becomes necessary to present the mechanical properties of this alloy in a form convenient for use in aircraft design. These properties include, in particular, the tensile and compressive stress-strain curves (in longitudinal and transverse directions in the case of sheet) and the "tangent modulus" or slope of the compressive stress-strain curve, which is important for estimating buckling loads.

J. A. Miller and W. R. Osgood of the NBS took part in this work, first by presenting carefully determined stress-strain curves and tangent modulus curves for a variety of sheet materials frequently used in aircraft and then by developing a convenient formula for describing most of these stress-strain curves and tangent-modulus curves. This formula requires the knowledge of only two "secant" yield strengths and the well known Young's modulus for a complete description of the variation of stress and of tangent modulus with strain.

Analysis of the stress-strain data also suggested presentation of the stress-strain curves and tangent-modulus curves in a dimensionless form, which makes them applicable to materials with similar properties, but with numerically different values of yield strength. This makes it possible to estimate the effect of using materials in a mechanical test with properties in excess of the minimum guaranteed properties. A set of dimensionless charts has been prepared recently for the NACA on aluminum alloy R301 sheet. Corresponding charts are being assembled for Alclad aluminum alloy 7SHT sheet and for other high strength sheet metals that are coming into use.
Stability of Extruded Stringers

Extruded sections are commonly used as longitudinal stiffeners or "stringers" in the "stressed skin" construction of airplane wings and fuselages. Both closed sections and open sections are used for this purpose. The open sections have an advantage over closed sections in requiring only one rivet line for attachment rather than two, and in being accessible to inspection. They have a disadvantage in being less stable. At high loads the open section stringer tends to buckle either locally or by twisting. It is important, therefore, to determine buckling loads of extrusions and to select an extrusion in any given case which remains stable up to the maximum stress to be carried in service.

The theory for determining the elastic buckling loads of thin walled open sections such as extrusions was worked out by W. Ramberg and S. Levy shortly before the war. It was decided by the Bureau of Aeronautics to check this theory by tests of extruded sections by themselves, and later with tests of extruded sections attached to sheet as in a sheet stringer panel. The first portion of the program has been completed and curves of buckling load versus length were obtained for aluminum alloy and magnesium alloy extrusions with a number of cross-sections.

Theoretical buckling loads were computed for all these sections taking due account of the stiffening effect of fillets and bulbs. The effect of plastic yielding was taken into account by reducing the critical stresses in the ratio of the reduced modulus, for a rectangular section, to the Young's modulus.

The computed buckling loads checked satisfactorily with the measured buckling loads. Accordingly the theory may be relied upon for estimating buckling loads for unsupported extrusions and it provides a good starting point for the analysis of extrusions attached to sheet.

The tests for this investigation were useful also in indicating that, in general, the Z section had the highest strength-weight ratio among the various sections tested.

Sheet Stringer Panels

The sheet stringer panel is regarded as the basic structural element in tests to determine the strength of the "stressed skin" covering of airplane wings and fuselages. Tests are usually made for convenience on flat rectangular panels loaded between "flat ends" in a compression testing machine. Such tests neglect the effect of the curvature of the stressed skin, which may be appreciable in the fuselage and in the forward portion of the wing section. The tests also neglect the effect of lateral pressure which may be important on the upper surface of the wing and in the case of integral fuel tanks.

End compression tests were made at the NBS on curved panels and on flat panels with a lateral load in order to determine these effects for the NACA. The tests showed that curvature increased the buckling load of the sheet in the panels appreciably, but that it had little effect on the load carrying capacity of the panel after the sheet had been allowed to buckle noticeably. Lateral pressure had a stabilizing effect also in so far as it raised the buckling load of the sheet between the stringers appreciably. However, the effect disappeared with the development of pronounced buckles and the load carrying capacity of the panels became practically identical with that obtained in the conventional end compression test without lateral pressure.

The tests indicate that it is usually adequate to test panels in end compression without the complications of curvature and of lateral pressure.

Extensive tests on flat sheet stringer panels were also made at the NBS for the Bureau of Aeronautics to improve the technique of testing panels and to make a detailed study of the various factors such as stringer spacing, rivet spacing, sheet thickness, length of panel, type of stringer, properties of the material which may affect the buckling loads and the ultimate load of the panel.

The results of most of the tests on flat panels could be combined into a simple
nomogram from which the strength of a panel may be estimated quickly by a designer provided the dimensions of the panel, the compressive properties of the sheet and the stringers and the rivet spacing are given.

**Plastic Bending**

A thorough understanding of plastic bending of beams is necessary for estimating the deformation of heavy beams which carry bending moments in the wings, fuselages, and landing gear of large airplanes. The curvature of such beams under bending moments, which stress the materials beyond the elastic range, depends on the shape of the cross-section of the beam and on the tensile and compressive stress-strain curves of the materials.

A general relation between bending moment and curvature was worked out by W. R. Osgood of the NBS for the Bureau of Aeronautics for a large variety of cross-sections and of stress-strain curves, on the assumption that plane sections in the beam remained plane after bending. Approximate methods were worked out also to reduce the computations necessary in practical cases.

The theoretical curvature versus moment curves were closely checked by tests made for the Bureau of Aeronautics on H-beams, T-beams, and beams of rectangular section of steel, brass, two aluminum alloys, and one magnesium alloy.

**Fatigue of Riveted Joints**

The stressed-skin cover of airplane wings and fuselages contains many thousands of riveted joints which transfer load from stiffeners and frames to sheet. Many of these joints are subjected to variable axial load because of vibration of the aircraft and the oscillation of the wings and tail during landing and take-off and in flight through rough air. The riveted joints are expected to carry these variable loads without developing fatigue cracks which might spread and lead to failure of the whole structure. Very few fatigue cracks have been observed in service on riveted joints in the aluminum alloys 179-T and 24S-T, which have been commonly used in recent years. No corresponding experience is available for the new high strength aluminum alloys developed in the beginning of the war. It was decided therefore to make fatigue tests of joints in these alloys and to compare their fatigue strength with that of the earlier alloys.

The NBS participated in this program at the request of the Bureau of Aeronautics and the NACA. W. C. Brueggeman made tests under alternating axial load on joints in the high strength aluminum alloys Alclad 765T and 8301T as well as in the older Alclad aluminum 24S-T. A technique had to be developed for these tests to prevent the riveted joints from buckling laterally when the alternating load became a compression of sufficient magnitude. This was accomplished with a set of lubricated wooden guides floating on the specimen.

The fatigue strength of riveted joints in Alclad 765T or 8301T sheet was found to be equal to or lower than the fatigue strength of Alclad 24S-T joints although the static yield strength and tensile strength of the sheet are higher.

Tests were made also with various values of rivet spacing and with different methods of driving the rivets. These tests proved to be useful in indicating an optimum spacing and in showing that rivets driven with a drop hammer had higher fatigue strength than rivets driven with a squeezer or with a pneumatic hammer.

**Reinforcement around Holes**

The stressed skin cover of airplane wings and fuselages has to be perforated by holes at a number of points to give access to the interior of the wing or fuselage. The metal around holes must be reinforced to prevent weakening of the entire structure by the hole.

An ideal reinforcement would be one which confines the disturbance in the "stress flow" to the immediate neighborhood of the hole and which at the same time adds minimum weight to the structure.

Too little is known about reinforcements to approximate this ideal in practice. Instead it has been customary to reinforce holes by circular doubler plates riveted to one side of the sheet thereby increasing the effective thickness and rigidity of the sheet at the edge of the hole.
The Bureau of Aeronautics asked the NBS to initiate a study of reinforcements around holes in order to provide a better understanding of reinforcements and to indicate practical improvements in the design of reinforcement. An analytical investigation by S. Levy was made of reinforcements of various shapes, including doubler plates, around a circular hole in a plate under uniform tension in all directions. The study indicated that a given weight of reinforcing material was most effective when crowded close to the edge of the hole. The same conclusion was reached in an analysis in which a plate with a circular hole reinforced with circular-doubler plates was subjected to tension in one direction and to shear.

The analysis assumes that the stress at any point of the reinforced plate is the same across the thickness of the plate. In actual reinforcements one may expect large variation in the stress in the thickness direction near rivets and at points where the thickness changes rapidly.

It was decided, therefore, to check the theory by tests on a large plate with a hole reinforced by riveted circular doubler plates of several sizes. The elongation of the hole and the strain in the plate were measured as the specimen was subjected to uniform tension at the ends. The tests showed good agreement between measured and calculated values provided at least two concentric rows of rivets were used to fasten the doubler plate to the specimen. Still better agreement with the plane stress analysis was obtained in a plate of sandwich construction with a circular hole reinforced by bonded circular doubler plates.

The results indicate that the plane stress theory can be applied to an analysis of doubler plate reinforcement provided that the reinforcement is properly attached to the plate.

**Magnesium Alloy Members**

Tests on bars, extrusions, wing beams, and panels of magnesium alloy were made for the Bureau of Aeronautics as part of an effort to develop alternative materials in place of the commonly used aluminum alloys. The development of alternative materials was especially important early in the war when a shortage of aluminum alloys threatened to develop.

Tensile and compressive tests were made on bars and extruded shapes from several experimental magnesium alloys. From the tests simple empirical rules were developed for estimating the compressive yield strength from the thickness and from the commonly measured tensile properties. Such rules were desired for rapid testing at the plant of the magnesium producer in connection with the development of new alloys. The tests showed evidence of excessive brittleness in several magnesium alloys, which made them undesirable in structures subject to impact loads and to vibration.

Compressive tests of magnesium-alloy extrusions gave buckling strengths for a given weight of specimen that compared favorably with corresponding values obtained on aluminum-alloy extrusions. Tests of wing beams under axial loads and transverse loads showed a strength for a given weight of beam equal to or better than that found for aluminum-alloy beams. Tests of sheet-stringer panels of magnesium alloy under axial loads also showed promising performance on a strength weight basis.

The results of the mechanical tests of magnesium alloys may be summarized by saying that magnesium offers promise for structural use in aircraft. No doubt magnesium-alloy aircraft structures would have been widely used during the war if the feared shortage of aluminum alloys had actually occurred.

**Monocoque Box Beam**

Monocoque box beams are used as the main strength member in the wings of most large airplanes since they combine high rigidity and strength in bending with high rigidity and strength in torsion. In flight, the monocoque box beam is subjected to various combinations of axial, transverse, and torsional loads. The stresses and deformations produced by these loads are computed in the "stress analysis" of the wing using formulas derived from the theory of elasticity. These formulas treat the monocoque box beam as a slender beam in bending and as a simple long tube in torsion. The formulas do not take
account of the presence of bulkheads, rivets and other discontinuities.

Tests on a monocoque box of typical design were made for the NACA in order to check stress analysis. The box was subjected to axial loads, transverse loads producing bending and shear, and torsional loads. Strains and deformations were measured at many points of the box and were compared with the values computed from the stress analysis. The box was then loaded to failure in torsion.

Excellent agreement with the stress analysis was found for the tests under axial loads and transverse loads provided a small correction was applied for the buckling of the sheet on the side of the box that was subjected to compressive stress. The test under torsional loads, however, showed large deviations from the theoretical angle of twist and the theoretical shear stresses. A more complete analysis of a monocoque box in torsion was accordingly worked out in which account was taken of the supporting forces applied by the internal bulkheads and of the axial stresses set up by the twisting of the box. The stresses and angles of twist computed from this analysis were found to be in good agreement with the measured values.

The tests have been useful in showing that the conventional method of stress analysis of monocoque box beams is adequate for compression and for bending, but that it must be modified or replaced by tests in the case of torsion.

**Stress Analysis of Rockets**

A stress analysis of the body of the 4.5 inch high explosive rocket M9 and the practice rocket M9 was requested by the Ordnance Department, U. S. Army, to explain results of field tests which indicated that it was desirable to make the body stiffer and stronger.

An analysis was made by S. Levy and W. Ramberg, which was confined to the forward portion of the rocket body since this was subjected to the highest stresses. The forward portion of the rocket was treated as an elastic cylinder subjected to internal pressure by the propellant and to axial load by the war head. The stress analysis was complicated by the presence of screw threads for attaching the war head to the rocket body, the presence of a bead for holding a cage with the propelling charge and the presence of a notch for confining rupture to a circumferential line at the base of the notch. Nevertheless, it was possible to obtain a solution from the theory of cylindrical shells by converting the differential equation for equilibrium of forces normal to the shell into a difference equation.

The solution confirmed the indication of the field tests in showing excessive stresses at the bead at internal pressures well below those at which yielding of the material in the notch could be expected. It also indicated considerable elastic bulging of the rocket body at the bead and at the threads. These results were also checked by tests at the NBS in which the rocket body was subjected to combinations of hydraulic pressure and axial load in a compression testing machine.

The immediate result of the stress analysis was to confirm the desirability of changing the design of the shoulder at the bead for carrying the cage with the propelling charge. A more general result was to provide a method for computing the elastic stresses in a rocket body.

An interesting byproduct of the stress analysis was an exceptionally compact and rigid dynamometer for measuring axial load which utilizes the property of the bead in the rocket body of developing high hoop strains under moderate axial loads. The Navy Department has applied for a patent on such a dynamometer.

**Army Equipment**

Mechanical tests of many items of equipment for the War Department, Army Service Forces, have been made for quality determination and for use in the preparation of purchase specifications. The partial list of articles gives in itself an indication of the scope of this work—Trench knives, pack boards and attachments, folding cots, nylon ropes, ice pitons, ski pole shafts, collapsible skis, airplane landing mats, gas cylinders, concertina wire splices, intrenching tools, glass vials for drugs, welded pipes for oil lines, welded steel beams, safety
shoes, crusher cylinders, glider towing cables, mortar shell fins, aluminum roofing sheets, thimble eyes, tent poles, ammunition covers, striker pins, steel balls and anti-tank mine fuses.

A knowledge of the strain values in all directions due to a load applied to an airplane is useful in utilizing the plastic as well as the elastic strength of the material in a plane. Many investigations of the stress-axis strain relations and of the value of Poisson's ratio in the elastic range have been made for aircraft materials but few data are available for the value of Poisson's ratio beyond the proportional limit. These values have been obtained, at the request of the Army Air Forces, for tensile axial strains up to about 20 percent stretch for aluminum alloy sheet material of various thicknesses for both 24-ST and 24SR-T alloys. Specimens cut in the direction of rolling as well as at several different angles have been tested. Similar values for one thickness each of a chrome-molybdenum and of a stainless steel have been obtained.

The failure of welded ships was a serious problem especially during the early part of the war. The fractures in the ships were of the brittle type and it was in general impossible to reproduce them in the laboratory so that the causes of failure could be determined. The NBS, in cooperation with the Structural Steel Committee of the Welding Research Council, designed and tested welded plates under conditions which produced brittle failures. The specimens were in the form of box girders having a weight of about 10 tons and a length of 23 ft, 4 in. The bottom of the box was made of lengths of 1 1/2-inch thick steel plates welded together and to the sides of the box and was the real part investigated. The stress distribution is probably complex in this plate, having residual stresses due to welding the plates together and to the side plates, and additional stresses due to the load applied to the girder. One girder was tested at room temperature and one at a temperature of -43°C. Brittle failures occurred in both cases. Strains were measured on more than 150 gage lines on each specimen. The stress-strain curves of coupon specimens, free from residual strains, were also obtained and found to have the usual ductile properties of mild steel. A comparison of the strains in the girder and in the coupons for known applied stresses is being made to determine the stresses existing in the girder before test which resulted in brittle failure in the girder as the additional stresses due to the load were induced.

Identification and description of materials and construction details of captured anti-tank and anti-personnel land mines have been written to be used as a basis for the preparation of Army Instruction Manuals. The mines were of German, Italian, and Japanese manufacture. Some mechanical tests were also made of the individual parts.

Bone Fracture Devices

At the request of the Surgeon General, War Department, studies have been made of bone fracture devices and especially of screws for holding the plates to the bones. The investigation dealt with the screwing-in torque, and initial holding force in the bone, of screws having different pitches; the relation of torque and holding force to variation in cortex thickness and to diameter of the predrilled hole; and the effect of flutes and of pretapping on these properties. In an operation to apply a plate to a fractured bone, it is desirable to have a small screwing-in torque and a large holding force. It was found that the pitch of the threads had little effect on the torque, that 3 flutes on a screw end decreased the required torque as compared with screws having a smaller number of flutes, that pretapping still more markedly reduced the required torque and that the torque increased as the predrilled hole diameter decreased until, with smaller holes, the screw twisted off or the bone was locally fractured. The initial holding force of a screw in a bone did not appear to depend on the thread pitch and varied but little as the predrilled hole diameter increased from the minor screw diameter until it was over 90 percent of the major diameter. With still larger holes the initial holding force decreased. Consideration of the process of decalcification in living bones due to large local pressures
between screw thread and bone indicates that the initial holding force cannot be used as a criterion of the permanent holding force. Experiments have therefore been initiated by using screws under continuing pressure in living bones to answer the questions relative to this aspect of the problem.

A citation from the Secretary of War was received by Dr. L. B. Tuckerman for his direction of this investigation.

**Calibration of Testing Machines**

For many war uses it was essential that materials should have a specified strength to avoid failures in service. To meet the greatly increased demand for mechanical tests of samples of the billions of dollars worth of war materials bought under rigid purchase specification many new testing machines were built and existing equipment was utilized much more fully than during normal times. It was important that new testing machines should be properly adjusted and calibrated before being put into service and that all testing machines be recalibrated periodically to insure the accuracy of test results.

Experience in using the inadequate calibration equipment available during World War I led to a search for an accurate portable calibrating device with sufficient capacity to calibrate average-sized testing machines to their full capacities. This work resulted in the development at the NBS of the Whitemore-Petrenko proving ring. Briefly the proving ring is an elastic ring whose deflection under load is measured by means of a micrometer screw and vibrating reed. When the relationship between the applied load and deflection has been determined by applying accurately known forces to the ring, it may be shipped by common carrier and used repeatedly to determine the errors of the indicated loads of testing machines. For applying accurately known forces to elastic calibration devices such as proving rings the Bureau has two dead-weight testing machines designed especially for this use. These are the only dead-weight machines available in the United States.

During the period from 1941 to 1945, elastic calibration devices were submitted for test at a rate of about 150 to 250 per year compared to a rate of 30 to 40 per year for the period from 1930-1935.

**Concrete and Concrete Structures**

Studies of concrete were carried on for the U.S. Engineers to determine how to maintain concrete warehouse floors subjected to heavy traffic, and how to improve the resistance of concrete to frost action. For the warehouse floors, treatments with chemical floor hardeners were specified and methods of refinishing the floors were prescribed. In order to improve the resistance of concrete to frost action, a thorough study was made of a commercial admixture for concrete which was subsequently found satisfactory enough for it to be recognized by the U. S. Engineers after the NBS had evaluated its usefulness with a number of different cements.

At the request of the U. S. Maritime Commission, two investigations were made by the Cement section concerning the improvement of cements for installations in merchant ships. One of these was to determine the proper type of cement for use in the bilge troughs of Victory ships. The materials studied were 3 oxychloride cements; a coal-tar derivative; and portland cement mortars to some of which various types of admixtures had been added to resist liquid penetration. After submission of these materials to a number of different tests intended to indicate their behavior in the conditions prevailing in actual use, plain portland cement mortar proved to be the most satisfactory for the purpose.

The other investigation concerned the proper quality, and proper methods of installation of magnesium oxychloride cement for interior decking of merchant ships. The use of this material is the standard practice of the Maritime Commission. Hereafter no specifications were available to control quality, with the result that the quality of installation was extremely variable. With the Bureau acting as an experimental laboratory to aid in
setting up standards and presenting methods of test, a specification was written by the Maritime Commission.

Concrete Oil Tanks

The shortage of steel plates for the construction of the customary type of steel tanks led to the use of concrete tanks for the storage of various types of motor fuels, even of high-octane gasoline. Liquid-proofing materials for the treatment of concrete were studied by the Cement Section of the NBS and the results were submitted in reports to the Army, Navy, and Maritime engineers. One form of liquid proofing was adopted by these agencies, in accordance with the Bureau's recommendation.

Since some engineers also expressed concern over possible large losses of high-octane gasoline vapor through the roofs of these concrete tanks, tests were conducted on the permeability of concrete test specimens to 100-octane gasoline vapor. Test specimens, made with varying proportions of cement and with different cement-water ratios, were tested for loss of gasoline vapor at temperatures of 40°, 70°, and 100°F for periods up to 4 weeks. Only slight differences in loss of gasoline were observed at the different temperatures, and the rate usually decreased with time of exposure. In general, the loss was greatest with the highest content of cement and with the greatest cement-water ratio. The tests indicated that the losses of gasoline through the concrete tank top would be of minor significance.

Concrete for Ships and Barges

With the threatened grave shortage in steel following our entrance into the war, officials of the Maritime Commission turned to reinforced concrete as a possible material for construction of barges and cargo ships.

The construction of vessels of reinforced concrete represented many problems in design, some of which required laboratory tests and investigations for their solution. There was apprehension regarding the resistance of the ship's concrete shell to impact loads, and information was needed relative to design details, such as adequate anchorage and splicing of reinforcing bars, in the limited spaces available in the concrete shell.

Slabs of light-weight aggregate reinforced concrete, the designs of which were similar to those proposed for the hulls of concrete ships, were tested by R. W. Kluge to compare their behavior under large impact loads. Following the development of a criterion of failure and a method of expressing relative resistance in terms of weight, it was possible to select designs on the basis of efficiency with respect to both over-all weight and the weight of the steel reinforcement.

The strength developed by various methods of anchoring bars—that is, by bending hooks of various degrees of curvature at the ends of the bars—was determined by C. C. Fishburn for plain and deformed reinforcement. The ends of the bars containing the anchorage were embedded in blocks of concrete with the other end of the bar free to be pulled in a testing machine. The data obtained showed the importance of bending the ends of plain bars to obtain satisfactory anchorage, but there was little difference in strength between the bent and the straight bar anchorage for deformed bars having tugs of appropriate height and spacing.

A common method of splicing reinforcement is to lap the ends of the bars within the concrete over a sufficient length to permit the gradual transfer of stress from one bar to the other. Since very little information was available regarding the nature of this stress transfer, a study was made to determine how the general behavior and strength of splices were affected by changes in the kind, length, and spacing of the bars. Splices in concrete beams were loaded in such a manner as to subject them to known loads. Data resulting from extensive strain measurements on the lapped bars clearly showed the manner in which stress was transferred from one bar to the other, as well as the effectiveness and strength of the splices.

Concrete Floors

At the request of the Repairs and Utilities Branch of the U. S. Engineers, inspections were made of the concrete warehouse floors at a number of Army posts, and
detailed specifications for the repair and maintenance of the concrete warehouse floors were developed. Assistance was also given in the development of specifications for the application of a colored concrete topping over existing wooden floors, particularly for use in hospital corridors and in mess halls.

Testing

During the 4 years of heavy war construction, the Federal Government used enormous quantities of cement for the building of Air Force and Navy bases, proving grounds, ammunition depots, concrete ships, camps and dry docks. Since the testing of a very large part of this material was in the hands of the NBS, under the supervision of P. H. Bates, the laboratories of the Bureau at Washington and the branch laboratories at Allentown, Pa.; Denver, Colo.; Permanenta, San Francisco and Riverside, Calif.; and Seattle, Wash., were subjected to an unusual strain—shown by the fact that over 60 million barrels of Portland cement were tested for Federal Government agencies, as compared to less than 6 million barrels in the previous 4-year period. This large amount of work was turned out in the face of many adverse conditions. Many new employees had to be recruited and trained in this specialized work. For the first time women were employed as cement testers and demonstrated their ability on arduous work requiring much manual dexterity. The laboratory was worked to its full capacity, the staff working 7 days a week on two shifts. In addition to testing, representatives of the Bureau were stationed at manufacturing plants to take samples and inspect the storage and shipping of cement purchased by the Government.

A branch laboratory was installed at Houston, Texas, to expedite the testing and shipment of cement for the third set of locks at the Panama Canal. Construction of the locks was halted because of the pressure of more important war construction, and the laboratory continued testing cement for the Southwestern area during the peak of the construction period.

The branch laboratories were also busily engaged in testing large amounts of miscellaneous materials, such as concrete and concreting materials, metals, petroleum products, paints, soaps, textiles, waters and soils. The San Francisco laboratory carried on a large paint testing program for the Maritime Commission merchant ships on the West Coast.

Sabotage of Concrete

At the request of the Army Intelligence Branch, War Department, a search was made for a readily available material which, when added in small amounts to concrete, would inhibit its gain in strength. It was suggested that this might be used by partisans in enemy-occupied countries to sabotage concrete fortifications and other military structures by mixing it in the concrete during construction. The treatment could not be too effective, for if too much of the concrete strength were destroyed, the result would be evident to the builders.

All the materials mentioned in the texts as inhibitors of strength were tested. Of all the inorganic salts, alkalies and acids cited, none were effective in reducing the strength over a period of time extending over several weeks, and in some cases the eventual strength of the concrete was improved by their use.

A number of organic materials such as dextrose and syrups were tried. The most effective agent as a strength inhibitor was common sugar. This, in fractions of one percent, was found to be very effective.

Expansion Joints

Because of the constantly increasing load imposed on military air field runways during the war, the Bureau of Yards and Docks, Navy Department requested the NBS to study the load-carrying capacity of expansion joints, which are spaced at regular intervals in concrete runways. One of the common methods of transmitting load across a joint is by doweling the adjoining sections of slab with round steel bars having a suitable coating to prevent their bonding to the concrete.

The problem was one of devising and testing various methods of reinforcing the concrete in the immediate vicinity of the dowel to resist the concentrated load transmitted
by the dowel. Dowels were embedded in reinforced concrete blocks with one end extending beyond the face of the block, and were loaded transversely to simulate service conditions. The data obtained were used in determining the optimum sizes and spacing of dowels for various conditions of service.

Hydraulic

One of the functions of the hydraulic laboratory at the NBS is to build and test models of proposed hydraulic structures, such as dams, spillways and locks. These model tests usually show ways in which the original design can be improved. Necessary changes can be made at small expense in the model, thus avoiding costly modifications of the full-scale structure. A number of interesting model tests, directed by H. N. Eaton, were made for the U.S. Navy during the war.

A proposed full scale steam-turbine testing laboratory at the Philadelphia Navy Yard was designed to take its condensing water from a nearly land-locked tidal basin about one half mile long and one quarter mile wide, and to discharge warm or hot water into this same basin. The purpose of the test was to determine whether currents of hot water from the discharge would flow to the intake and thereby limit the use of the laboratory, or even make it impracticable in the desired location. A model of the basin was constructed on a scale of 1:80, with circulation and heating systems to represent the proposed laboratory as well as two smaller laboratories already in operation. The model was furnished with a tide-reproducing system, thermo-couples, and thermometers and recording level gages. The hot water currents were made visible by milk injected into the circulating pump representing the laboratory.

Thermo-couples, adjustable in height, were mounted on beams spanning the model. Wood floats were pivoted on wires so that the directions of surface currents were indicated. The tests showed: (1) that the laboratory could operate indefinitely at full power if the average initial temperature of the basin was not over 75°F, (2) that a slow temperature rise at the cooling-water intake would start after about three hours of continuous operation, but this temperature rise would reach its maximum after about 5 tidal cycles; (3) a somewhat better location for the discharge than that originally selected. The work, completed in 3 months, is considered to be unique in its combination of hydraulic and thermal effects.

Two days after Pearl Harbor, the Bureau of Yards and Docks authorized model tests of the filling system designed for a very large new dry dock at Pearl Harbor. On February 13, 1942, a similar test for a dry dock at Hunter's Point, California, was authorized. Results of the tests and final recommendations were submitted on June 26, 1942.

Gravity filling systems were designed for these dry docks, consisting of intakes at each side leading to conduits running down through the walls to a cross conduit under the floor. From this, branches led to openings or ports in the floor of the dock just inside the gates. The first tests showed that the systems discharged the expected quantities of water. However, practically all of the water issued from the ports in the center of the dock and very little from those near the sides. Moreover, the height of the largest jet in the model corresponded to a height of about 35 feet in the prototype. The main problem was to provide an even flow from all the ports with the designed capacity and with low jets. Changes were made in the model which gave jets uniform in volume and only ten or twelve feet high in the prototype. When the dock was completed, the actual jets were less than ten feet high. An incidental result of the tests was the elimination of very large quantities of cast iron conduit at a time when shortage of materials and congestion of transportation were critical.

Model studies of concrete mooring anchors were requested by the Bureau of Ships on July 9, 1942. Preliminary designs of two types of such anchors had been made but there was no way of computing their holding power or stability. Most of the tests were made on models built to a scale of 1:8, but some on scales of 1:12 and 1:4 were also included. For testing, the models were placed on a sand bed under water and dragged by a special winch at very slow speeds—one foot per
minute or less. A dynamometer showed the force necessary to move the model. The model, in all cases, slowly dug into the sand to a certain depth—depending on its shape—at which point the pulling force reached its maximum and became constant. For anchors of the same shape this force was proportional to the volume (specific gravity being the same). Stability was tested by placing obstructions of various sizes and shapes in front of the anchor. One original design was immediately discarded because the tests showed that it was inherently unstable. The other form was quite stable and developed a fairly high holding power. It was found possible, by slight changes in design, to increase the holding power by a factor of 3 over the original design without excessive reduction of longitudinal stability. The work was completed in February 1943.

Sound Measurements

The Sound Section was requested by the War Department to develop walls that would transmit sound distinctly. Work in this field is usually directed toward securing partitions that will transmit as little sound as possible, so that the problem was of unusual interest. The object was to develop a partition that would enable Intelligence officers to listen to what prisoners of war were saying when confined in quarters having walls that appeared to be massive and solid. A partition was constructed which would transmit the sibilant sounds required to make speech understand-}

able. The conversation transmitted was picked up by a special microphone having an unusually high sensitivity.

The acoustic properties of a special ear defender, developed for use by artillerymen to protect the ear against the noise of gunfire, were measured for the War Department. Unfortunately, this ear defender was not constructed on valid acoustical principles and actually permitted the passage of sound pressures as high as 5,000 times the pressure at the threshold of hearing. The measurements showed clearly that it did not provide a practical solution of the problem.

The experience of the Sound Section in making absolute measurements in sound intensity enabled it to carry out the absolute calibration of microphones used by manufacturers of interphone equipment for the Armed Forces. Similar absolute measurements were made on the outputs of receivers used as a part of interphone equipment.

At the request of the War Department, a study was made of the sound absorption of the ground after it had been disturbed by the burying of a mine. The object was to try to work out a scheme for locating nonmetallic mines that could not be found by the usual mine-detection techniques. The measurements showed that the ground is as a rule a good reflector of sound even after it had been disturbed by the burial of some object. The differential sound reflection of disturbed and undisturbed soil was not great enough to give positive evidence of disturbance and the project was discontinued.
11. Optics, Color, Light

Literally hundreds of problems associated with the fields of optics, photometry, and colorimetry arose during the war and were referred to the Bureau for their solution. In all of these fields the Bureau had been active since the early years of the century, and the staff and facilities of the Bureau were devoted to the special problems of the Armed Services.

The continuity of work at the Bureau was fortunate, for many problems that ordinarily would have required extensive programming and the acquisition of staff and facilities were promptly attacked. A typical situation in which these factors prevailed was that of optical glass. The Bureau has maintained the only laboratory in the world in which optical work begins with the raw materials of the optical glass and proceeds to the finished optical device.

The need for facilities of this type became apparent shortly after the opening of the first World War. At that time, equipment for the production of optical glass was installed at the Bureau under the sponsorship of the Navy. The work in this field as well as in other phases of optics was intensified during that war and was continued in the interval of peace between the two recent wars. The Bureau was thus prepared for the emergency requirements of World War II.

Optical Glass Production

During the years between World War I and World War II the NBS was the only research organization in the U.S. engaged in research and production work on optical glass. This work was supported chiefly by the Bureau of Ordnance of the Navy Department, who saw that it was desirable to foster the continuing production of this critical war material, not only because of the small peacetime demand but because many domestic optical-instrument makers found it economically advantageous to import a substantial portion of the optical glass they used.

With the outbreak of war in Europe in 1939, there was a sudden increase in demand for optical glass, and the wisdom of the Navy Department in helping to support a small Government-owned plant for making optical glass was at once evident. Not only was it possible for the National Bureau of Standards to expand its facilities rapidly, but assistance could also be given to others who were starting the manufacture of optical glass without previous experience.

Prior to 1940, all the optical glass being produced at the NBS was being supplied to the Bureau of Ordnance for use at the Naval Gun Factory. The quantities delivered up to that time never exceeded 9,200 pounds a year. The quantities produced and delivered during the war years were as follows:


This glass not only met the very strict specifications of the armed services as regards refractive index, dispersion and freedom from optical imperfections, but it was molded before delivery into various prisms, and concave and convex lenses in order to minimize subsequent grinding operations. As a final step all the blanks were carefully annealed to remove any distortion arising from internal stresses. Some of the molded lens blanks, such as those for binocular eye-pieces, were very small, weighing 80 to the pound.

Optical glass was made during the war under the direction of A. N. Finn and C. H. Hahner for the Bureau of Ordnance, Bureau of Ships and Bureau of Aeronautics of the Navy Department, the Army Ordnance Department, the Corps of Engineers, the Procurement Division of the Treasury Department, and OSRD.

In 1939, the NBS had less than 20 people engaged in research and production work on optical glass. This staff was expanded until at the height of production, over 400 were employed. Since no experienced people were available except the original staff, all others had to be recruited and trained for the work. Many of those hired and partially trained were drafted into the armed forces, so that it was necessary to hire and train replacements constantly during the entire
period. For many jobs it was possible to use women, but only men could work around the hot furnaces. The problem of adequate help was always troublesome since the plant was operated on 3 shifts and so the experience of help was spread very thin.

Only limited equipment and space were available for this work at the start. In 1940, an addition to the kiln building was built which added 12,000 square feet more floor space. In 1942 the Bureau of Ships erected an additional building on the NBS grounds for the manufacture of optical glass. This building had about 2,000 square feet of floor space and was built so that it could be completely blacked out for night operation. Three additional glass melting furnaces and all the necessary auxiliary equipment such as batch mixing, molding and annealing equipment were installed in this new space.

The most critical time in optical glass production was the earlier part of the war. By the summer of 1944 there was a cutback in production requirements, and the full production of the commercial optical glass plants, as well as the NBS plant, was no longer required. Demands increased sharply in December 1944, because of the German counter-drive, but decreased again sharply with the approach of the end of the war in Europe. With the end of the war in Japan, NBS stopped the production of optical glass except for a small quantity furnished to the Bureau of Ordnance for use by the Naval Gun Factory. During 1944 and 1945, the National Bureau of Standards was supplying mostly special items for which some of the commercial plants did not wish to accept orders because of the small amount and the rapid delivery rate required, or because the glass was of an unusual type. Since that time operation has reverted to the pre-war fundamental research basis.

In 1940 the National Bureau of Standards was approached by the National Research Council of Canada regarding assistance in starting optical glass production in that country. Engineers and scientists from Canada studied NBS equipment and were given all possible assistance. The first successful melting of optical glass in Canada was started by Research Enterprises, Ltd., in 1941. Much of the information obtained from the NBS was used in the design and operation of this plant.

Early in 1941, similar assistance was given to scientists from the Australian National Standards Laboratory and to the Ministry of Munitions of the Commonwealth of Australia. Successful production of optical glass was started by the Australian Window Glass, Ltd. in September 1941.

In our own country, a substantial amount of technical assistance was given to the Hayward Optical Glass Co. of Maywood, Calif., and to the Libbey-Owens Ford Co., of Toledo, Ohio. Neither of these firms had had previous experience in specialized optical glass manufacture. They were able, however, to start production in a remarkably short time and to furnish optical glass during that period of the war when it was most urgently needed. The Libbey-Owens Ford glass Co., which had undertaken the manufacture of optical glass solely as a contribution to the war effort, discontinued it in September 1944, when they felt that their production was no longer needed.

At the start of the war only 8 types of glass were being furnished to the Bureau of Ordnance, Navy Department. During the war period 28 types of glass were furnished to the various Government agencies for use in instruments. Many of these types had been made by others and there was published information in the literature on compositions, annealing temperatures and other physical properties. In such cases little development work was necessary before satisfactory glasses of these types could be made. In other cases the glasses were of entirely new types, concerning which published information was lacking or inaccurate. In such cases the Bureau first designed the glass on the basis of the known values of the effect of the various oxides on optical properties such as index of refraction and dispersion. A trial melt of about 60 grams of glass was then made in a platinum crucible. Measurement of index of refraction, dispersion, liquidious temperature, softening point, stability of the glass and other properties could be made on this small sample before full scale melts
were undertaken. The first full scale melts of new types were usually not entirely successful since estimates had to be made of such factors as volatilization rate and pot solution, but usually the second or third full scale melts of new types of glass yielded considerable quantities of usable optical glass.

In the manufacture of optical glass the object is to produce a glass that not only has the desired optical properties and stability, but one which is entirely homogeneous. The main defects in this respect are what the glassmaker terms "seeds" and "striae," the former being small bubbles and the latter fine threads of glass of slightly different indices of refraction than the main body of the glass. Both these defects are present to some extent in almost all optical glass, but when they become excessive they interfere with the performance of the optical elements in instruments. A great deal of work was done on the improvement of the melting schedules to increase the yield of glass of good quality. Among the factors studied were: (1) effect of furnace atmosphere and pressure on seeds; (2) effect of the stirring speed on seeds and striae; (3) time-temperature relations for various stages of the melting; (4) selection of the proper exit temperature and cooling procedure after removal of the pot from the furnace.

Empirical time-temperature relations for various parts of the melting schedule were worked out largely by following the progress of the melting and fining with dip samples from the surface of the glass. The proper exit temperatures for the various types of glass were also determined largely empirically by a study of the results obtained in the finished melts. However, knowledge of the viscosity data was always helpful and in some cases the liquidus temperature was the determining factor.

The quality of the optical glass with respect to striae was also affected by convection currents after removal of the pots from the furnaces. A study of the temperature distribution and the tracing of the movement of the glass by means of particles of coloring oxides introduced into the glass helped to solve the problems of cooling after removal from the furnace, and by trial of various techniques, methods were found to reduce the convection currents causing harmful striae.

The development of a rapid method for measuring the index of refraction and dispersion of glass which eliminated the necessity for grinding and polishing samples was of considerable assistance to the optical glass work, especially in the control and development of new glasses. An immersion method was developed whereby the index and dispersion could be measured in about 1-1/2 hours. The glass sample was matched to an immersion liquid using double diaphragm oblique illumination. The index of the liquid is then measured on a precision refractometer. The limiting factor in the accuracy of the index measurements with this apparatus is the precision of the refractometer. Results of a large number of measurements show that the refraction can be determined with an average error of $1.9 \times 10^{-5}$. Dispersion as represented by $V$ value can be calculated from these measurements with an average error of ±0.1.

In the years intervening between World Wars I and II, the manufacture of optical glass was continued on a small scale and the clay pots for that purpose were made by the NBS Refractories section. Because of this continuing production, the Bureau was prepared to increase the size of its pot manufacturing facilities quickly so that the number of pots produced rose from 70 to 2300 annually.

To accomplish that result required considerable expansion in floor space and the installation of equipment without interfering with the then current production. Eleven concrete bins for storage purposes were built, the largest of which accommodated a carload of clay. A small, practically dust-free plant was erected for crushing, grinding and screening reclaimed pot shell into four fractions which could be operated continuously with the services of only one worker. An elevator was installed for hoisting dump carts to small bins from which the ingredients for the pot batches were taken and
weighed on a scale suspended from an overhead trolley. A blunger suitable for sufficient batch materials for four pots was obtained and mounted so that it could be loaded from hoppers raised over it by an electric hoist. Storage was provided for approximately 276 finished pots weighing 700 pounds each.

The two types of pots, one with a low porosity lining approximately 1/8-inch thick and one without, which were in production at the beginning of the war, were made by casting the clay slip in plaster molds. Although the behavior of both types was quite satisfactory in melting the glass for which they were intended, improvements led to a great reduction in the penetration of the glass into the pots and the elimination of the occasional leakage of the glass through the pots. In the case of the unlined pots a study of the size-grading of the grog grains to produce optimum bulk density led to a change in the size distribution which greatly lowered the permeability of the pots without significantly reducing the porosity or resistance to thermal shock.

Passage of the glass through the lining was primarily a result of defects such as invisible air pockets or cracks in the lining. These promoted the formation of channels for the molten glass, of which the more corrosive varieties would tend to run readily through the pot bottom. For such glasses, pots were successfully developed which contained a lining approximately 3/8-inch thick composed of two or more separate coatings.

**Optical Instruments**

**Range Finder Investigation**

The Optical Instruments Section under I. C. Gardner undertook a fundamental investigation of the design and performance of range finders. A special range-finder laboratory was constructed to house a testing instrument of new design, capable of measuring angles to the nearest second. Provision was made for complete temperature control to permit tests at any stable temperature between 0° and 120° F, or with the temperature changing at a fixed rate. Measurements can be made on simulated targets at a series of different ranges and at any altitude from 0° to 90°. This equipment has been used to test instruments of American and foreign origin and is now being used to test new experimental models as they are completed by American manufacturers.

The NBS was first in this country to submit proposals that range finders be designed in such a manner that the effects of temperature change will be almost if not completely compensated, thus eliminating the requirement for change of adjustment with each change of temperature. The Optical instruments section has under construction two range finders of improved and advanced design, and two additional experimental models being built by commercial firms following design proposals originally submitted by this Bureau.

An analysis of the error structure of a range finder has been formulated and quantitative measurements have been made of the errors of range finding that have their origin in the heterogeneity of the external atmosphere and in the personal bias of the observer. These errors are of fundamental importance and their measurement will greatly influence the future design of range finders.

**Long-Focus Lenses**

Early in the war, the Optical Instruments Section was asked to design and construct two long-focus photographic objectives (40 and 50 inches respectively). These lenses were produced and performed satisfactorily. The definition was as good or better than any long-focus camera lens that had been produced at that time, the 50-inch lens showing people on the streets and distinguishing the separate railroad ties from an altitude of two miles (10,000 feet).

**Testing of Airplane Camera Lenses**

Shortly after the end of the first world war the NBS, at the request of the Air Corps, undertook the testing of airplane-camera lenses of German origin captured by our army. Continuously since that time the Bureau has been actively engaged in devising better methods of test and in testing airplane camera lenses for the different Government departments. Methods entirely novel and testing instruments that are unique in this
country have been designed and constructed. Our test methods, or variations of our methods, are now generally used and our method of designating distortion is slowly but certainly replacing the older percentage measurement not only in this country but abroad. During World War II, airplane cameras in large quantities were tested both for the Army and the Navy and the instruments were widely used. In particular they were used in constructing maps by the Navy for the hitherto uncharted islands of the South Pacific which were photographed and mapped while still in the hands of Japan.

Refractive Indices of Optical Glass

The primary refractive-index measurements for control of the optical properties of all optical glass made at the NBS during the war were made in the Optical Instruments section. Strictly speaking, commercial refractometers are inadequate for acceptance tests on optical glass for precision uses. On the other hand, accurate spectrometric determinations on the large volume of glass manufactured during war time are prohibitive and it was necessary to rely to some extent on precision refractometer measurements of refractive index. The critical-angle refractometers were, however, used strictly as comparison instruments and every fifth melt of crown glass of each type, and every tenth melt of flint glass, was measured on the spectrometer in order to obtain accurate measures of dispersion and check the overall accuracy of the refractometer procedure.

Glossmeter

The surface roughness of an artillery shell affects its flight characteristics. The Office of the Army Chief of Ordnance in December 1943, asked the NBS to assist in the development of a simple production-inspection method for measuring the roughness of machined artillery-shell surfaces. Since shininess is one indication of surface smoothness, a photoelectric glossmeter was developed and tried for the purpose. Because the roughness of shells was much larger than the smallest roughness that affects gloss, it was necessary to coat each surface measured with a thin film of light oil which would fill the microscopic cracks, pores, and irregularities. On specimens thus coated, readings could quickly be obtained with the small portable glossmeters. These gloss values were found to correlate satisfactorily with ratings of surface smoothness obtained by other means in roughly one thousand shells which were studied. The possibility of adopting the gloss method for measuring surface smoothness of artillery ammunition was still under consideration at the cessation of hostilities.

Blackout Devices

The development of blackout and dimout devices was necessary as a protection against possible air raids in the early part of the war and as a protection along the coasts against submarines and other naval craft. In this blackout work the NBS cooperated with the Office of Civilian Defense and the War Department. At the request of the OCD, Bureau personnel served as chairman of OCD committees on Window Obscuration (K. S. Gibson, Chairman) and Headlamp Masks for Motor Vehicles, (R. F. Teele, Chairman).

The Bureau measured the luminous transmissions of approximately 150 samples of blackout cloth, paper, paint, and other materials. The transmissions of such materials designed for blackout purposes are so low (0.003 percent, maximum that a special photometer had to be constructed to enable the measurements to be made with the desired precision and accuracy. As a result of these activities the OCD issued a specification "For Window Obscuration for use During Periods of Blackout," containing sections on light transmission requirements, fire safety, and weather resistance.

During the war there were 3 different driving conditions encountered: (1) Driving in areas not visible to the sea but where upward light must be eliminated to avoid skyglow (which aids enemy submarines in detecting boats plying offshore routes); (2) driving in areas visible to the sea where the headlamp must be so designed that it is not visible from the sea so that ships will not be exposed to enemy submarines by occultation; (3) driving during blackouts.
A mask was developed to be used over existing headlamps, which by means of simple changes gave 3 beams, one for each of these conditions. Several manufacturers became interested and produced pilot models for War Department approval, and the Office of Civilian Defense was prepared to recommend the mask for essential civilian cars during air raids if requested by the War Department.

During the course of many tests of automotive lighting devices for the Army, the NBS made an improvement in Army blackout headlamps, which on the basis of one million units (since every military vehicle from motorcycles to the largest built was required to have one) would save 2,490,000 pounds of steel, 2,000 pounds of zinc, 25 pounds of aluminum, 5,090 pounds of brass, 16,500 pounds of rubber, and 1,800 pounds of bakelite, and which would also give better illumination than the unit then in use. The simplicity of design conserved man-hours in fabrication, permitted liberal manufacturing tolerances, and resulted in a unit less costly to build.

In night driving under blackout, freedom from detection by hostile observers in airplanes is the primary consideration. In combat zones the additional requirements of freedom from detection by hostile observers on the ground is imposed.

The use of a so-called black light (near ultraviolet) to activate fluorescent markers of the retrodirective type and phosphorescent markers was tried out in a series of tests at Camp Lee, Virginia. The opinion of men with combat experience was that they desired some sort of invisible light, regardless of any advantages of devices such as the standard blackout headlamp. It was found possible to delineate a course with retrodirective fluorescent markers so that men who had never seen the route could follow it at night when the vehicles were equipped with units emitting ultraviolet light.

The NBS assisted in a joint Army-Navy program of field tests devised for the purpose of obtaining basic information concerning the characteristics of sky glow from artificial sources; evaluating the extent to which sky glow and shore lights were a factor in aiding enemy submarines; establishing amount of sky glow produced by various types of lighting and the degrees of dimming required of such lighting; and investigating the utility and practicability of light-control methods. The Bureau designed and supervised the installation of equipment for measuring the transmission of the atmosphere in the field, using standard Army equipment, and made photometric observations during the field tests.

The Bureau cooperated with the War Department in establishing various requirements for blackout. Many of these were printed and distributed by the Office of Civilian Defense. The requirements affecting most civilians were those for street lighting, buildings, and highway movement. Others were of primary concern to the Army, as for example the blackout of railroads. Although it never became necessary to blackout the railroads in this country, the Supply services operated railroads in the combat zones and consequently had to make use of the requirements for satisfactory blackout.

Results of this work appeared in five specifications: (1) Street Lighting During Blackouts; (2) Blackout of Buildings; (3) Blackout Requirements for Highway Movement, issued by the OCD; (4) Blackout of Railroads; and (5) War Department Blackout Standards, issued by the War Department.

Camouflage

Throughout the defense and war periods, groups from the military services came to the National Bureau of Standards for help in preparing methods of test to assure that camouflage materials had suitable appearance and resistance to fading. Methods of gloss measurement, reflectance measurement, and fading measurement were all developed at the NBS during the period immediately before the war. These test methods and the experience gained in their preparation were widely applied to the services' problems of testing camouflage finishes.

Most camouflage finishes must be dull and so possess practically no gloss. The desired finishes proved to be so dull that it was difficult to measure their gloss with accuracy using the customary high-gloss standards
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developed by the Bureau for the American Society for Testing Materials. To meet this need, a new set of low-gloss standards was developed and over 10,000 were issued to testing agencies and manufacturers for use in the gloss measurement of camouflage finishes.

Camouflage finishes must also possess suitable resistance to fading from the combined action of weather and sunlight. To evaluate resistance to fading, widespread use was made of accelerated-fading units, a multipurpose reflectometer developed by R. S. Hunter in 1940, and a method of evaluating small color differences developed by D. B. Judd in 1939. Painted strips of osnaburg such as was woven into the netting covering guns in the field, steel panels coated with vehicle paints, and other samples of camouflage materials were measured with the multipurpose reflectometer before and after exposure to artificial weathering. From the data thus obtained, the amounts of color change caused by exposure were computed in NBS units of color difference. Because it was thus possible to obtain numerical measures of fading, permissible amounts of fading for these materials were included in many specifications. Workable instructions for fading measurements which would be properly interpreted and executed in testing laboratories were prepared for use with a number of types of camouflage materials.

Early in the war when the camouflage of large installations such as airfields and factories was undertaken, it was discovered that the use of coating materials of the proper texture was more valuable in producing deception than the use of materials of the proper color. Coarse materials such as wood chips, steel wool, and gravel were therefore colored and spread onto airport surfaces and factory roofs to give these surfaces the appearance of the surrounding areas of vegetation. During this period, no method existed for evaluating texture and therefore texturing materials were selected and applied on a guess-and-try basis.

Because of the interest of the Army Engineer Board in this problem, the development of a method for evaluating texture photometrically was undertaken. A photoelectric illumination meter was built to make outdoor measurements of the amounts of light reflected by sunlit surfaces in different directions. Measurements with this meter showed that texture is what might be called "negative gloss." Textured surfaces have many cavities. Because only those cavities exposed to the sun are filled with sunlight, a textured surface appears brightest when observed from a down-sun direction. On the other hand, a smooth horizontal surface, such as is obtained by merely painting an airport runway, appears brightest from an up-sun direction because even the dullest paints have some gloss. By means of this meter it has become possible to evaluate quickly the degree to which a natural texture is duplicated by any given texturing material.

The effectiveness of camouflage measures for ships may be determined with good reliability by observations of accurate scale models of the ships under controlled conditions in a visibility theater. The pertinent variables are: (1) Horizon-sky brightness, which determines whether it is a daylight, moonlight or starlight scene; (2) brightness ratio of sea to sky, which must be adjusted for roughness of the sea and haziness of the atmosphere to be duplicated; (3) sun or moon ratio, which gives the proportion of directed illumination to the total and must be adjusted to the cloudiness of the sky to be duplicated; and (4) brightness of intervening haze. A digest of classified British reports was prepared for the Bureau of Ships showing the results of British measurements of these variables and the methods used by them to incorporate the corresponding adjustments in a visibility theater.

A poorly camouflaged ship may become visible even when most of the hull is below the horizon. The study of effectiveness of camouflage for various ranges and heights of observation requires a knowledge of the distance to the horizon as a function of height of observation. Curves showing this function were prepared for the Bureau of Ships in 4 scales, those pertaining to ship models, to full-scale ships, to aircraft, and to inter-planetary heights.
Camouflage Materials

At the outbreak of the war and during the troop training period previous to the war, the Army was using a cold-water protein-binder paint for camouflage purposes. This paint was unsatisfactory in many respects, such as difficulty of application in the field and deterioration of the paint in storage. A better camouflage paint was urgently needed.

An emulsion paint was made in the NBS paint laboratory under E. F. Hickson and R. F. Tener for several manufacturers. The paint in general consisted of a vehicle containing a combination of oils and resins dispersed in suitable organic solvents, pigments necessary to meet the color and durability requirements of the Army Engineers together with suitable emulsifying agents, driers, mildew agents, low temperature solvents, and other ingredients to produce a product of the highest grade.

No experimental procurement of the paint was possible under specification because of the urgent need for the paint in the field. It was early realized that the problem was not one of testing or inspection, but one of developing a camouflage paint that could be produced in large quantities and at the same time obtaining for the Army an acceptable paint in sufficient quantity.

Some of these earlier difficulties are illustrated by the following:

1. It was thought that the paint should penetrate the fabric to a high degree as is customary in other fabric treatments. This was found to be incompatible with both color and durability; hence, it was necessary to change to a paint that penetrated enough for good adhesion, but in the main lay on the surface of the fabric.

2. Both a durable and stable paint was desired but these were found to be opposing factors, since good stability produced poor durability and vice versa. It was necessary to produce a delicately balanced emulsion in order to obtain a paint satisfactory in both of these respects.

3. The so-called drop test was proposed as a method for determining whether the emulsion formed with addition of water was of the oil-in-water or water-in-oil type. This test could not be interpreted or reproduced in any one laboratory or among laboratories, hence the decision had to be based on the results obtained by making a practical application of the paint to cloth.

4. It was found that the paint varied in the amount of color change resulting from the stability tests and the accelerated weath-er tests. It was impossible to grade them as satisfactory or unsatisfactory and still have any meaning to anyone other than two or three graders at the NBS. This meant that the final grading of color had to be kept in one laboratory if reproducible results were desired.

The difficulties with respect to color changes were overcome by developing a method of measuring color differences on fabrics with the aid of R. S. Hunter's reflectometer. This gave the difference in color as a numerical value. Thus, changes in color could be given to manufacturers and the Office of Chief of Engineers without trips to the National Bureau of Standards to compare samples. This method was a revolutionary departure from the limited visual examination method. It was the first time that the reflectometer had been used for measuring color differences of coated fabrics in a specification.

As a result of these developments, a specification was prepared for an oleo-resinous emulsifiable paint which could be thinned with either water or gasoline and could be applied to cloth, metal, or wood. It did not leach out in water or grow mildew. The emulsions are stable and withstand, without adverse effect, a temperature of 180°F for 2 weeks (samples of paint were aged for more than 19 months and were still stable), a temperature cycle of from -40°F to 160°F; and it mixed with gasoline at 0°F. The coated fabric also withstood accelerated weathering for 300 hours in the weatherometer.

Approximately 5,000 samples were tested, which involved about 5,000,000 gallons of paint having an approximate value of $9,000,000. The development of this oleo-resinous camouflage paint is considered by the paint industry as a signal development in the field of decorative and protective coatings.
Another development in the camouflage field was a material called shrimp nets. These nets were manufactured by companies formerly engaged in the manufacture of lace, curtains and similar materials.

These nets were of two colors, sand and olive drab, and were used to camouflage motor vehicles, such as trucks, jeeps, automobiles, motorcycles, primarily when parked, and for garnishing Army helmets. They are light in weight, do not need regarnishing, and are much less bulky than the garnished fish net.

These nets also were the first camouflage materials to be flameproofed. In addition to tests for fire resistance, the nets were tested for resistance to mildew, accelerated weathering, construction, strength, and effects of heat.

An extensive procurement program involved the testing of impregnated fabric, mainly impregnated jute burlap, with a limited amount of impregnated osnaburg cotton and massilon paper.

The burlap was usually impregnated with a water-in-oil emulsion system containing desired pigments, solvent, mildew-proofing agent and water. The initial samples lacked the desired color intensity, grew mildew, and were not very durable. After further development, subsequent procurements improved very greatly. They also were impregnated with a flameproofing compound. Approximately 10,000 samples of impregnated camouflage fabric were tested.

In August 1940, at the request of the Army, the Photographic Technology section under R. Davis undertook the preparation of a camouflage paint to be used in applying identification symbols or numbers to military vehicles which would be visible to the eye against the standard olive drab ground paint, but which would not be visible in aerial reconnaissance photographs.

Aerial photographs are taken on a pan-chromatic film in conjunction with either a yellow or red filter to reduce the effect of atmospheric haze. The problem, then, was to devise a paint of such spectral distribution of reflectance that, when photographed under these two conditions, its photographic brightness would be the same as that of the olive drab paint, while at the same time it presented the highest possible visual color contrast. This condition is met by a particular pale blue color.

After some experimental tests, using pigments available at the NBS, a mixture was found which met the requirements. The Quartermaster General's Office reported, however, that these particular pigments were not available in sufficient quantities. They supplied the NBS with similar pigments and paints as were available, together with sample panels painted with the standard olive drab. Experimental studies were carried out with these materials, each experimental mixture being photographed outdoors on pan-chromatic aerial films through each of the two filters. A mixture was found which met the requirements satisfactorily, i.e., which was practically invisible when photographed against olive drab with either filter and which exhibited a good color contrast against olive drab. This paint was adopted by the Army and was used extensively throughout the war.

Transmissometer Application

In every full-scale test of the effectiveness of a concealment measure, or the visibility of a signal, light transmission of the atmosphere is a vital element. Frequently this transmission varies from hour to hour so rapidly as to obscure the effect of all other variables, including those under study. The visibility and camouflage tests of the Navy and War Departments in the first years of the war were greatly handicapped by visual estimates of atmospheric transmission, expressed in such terms as foggy, hazy, or clear. In the summer of 1943, the importance of a continuous automatic check of atmospheric transmission was realized, and the Bureau of Ships requested the assistance of the NBS on this problem because of prior experience in developing and testing a transmissometer for the Civil Aeronautics Administration. This transmissometer consisted of a regulated light source, a photoelectric receiver placed from 600 to 16,000 feet away, and an indicating unit which automatically provided a continuous record of the light transmission of the atmosphere.
The Civil Aeronautics Administration made available all equipment and information useful to the Bureau of Ships. One transmissometer was moved from the airport at Indianapolis to the Naval Air Station, Banana River, Florida, where it furnished atmospheric transmission data for a two-months secret test. Two new transmissometers ordered by the Navy Department for the Naval Air Station at Patuxent River from NBS designs were inspected and installed, one on a 4,000-foot range for the Camouflage Section of Tactical Test, the other on a 660-foot range for tests of approach-lighting and other airport-lighting equipment. The NBS also undertook to design and build two types of portable indicators for the Navy.

At the further request of the Bureau of Ships and the National Defense Research Committee, a transmissometer was installed on a 3,000-foot range over water at Oyster Bay, Long Island, in the fall of 1943. This instrument was maintained primarily by NBS personnel until September 1946, and was used in camouflage and visibility tests for NDRC Section 16.3.

Naval Aircraft Lighting

Antisubmarine Aircraft Searchlights

Aircraft radar is able to locate submarines on the surface of the water at night, but the signal reflected by a submarine cannot be distinguished from that reflected by such small surface craft as fishing schooners or even destroyers, especially at ranges sufficient to initiate an attack during the approach. The British introduced the use of a searchlight on an aircraft as a means of providing the necessary identification of the located vessel.

Although anti-aircraft and battleship searchlights have the necessary intensity to illuminate a vessel, their size, weight, and power requirements make them impractical for use on aircraft. The first planes equipped with searchlights by the British used such units but only special bombers could carry them. Confirmed sinkings of German submarines on the first operational flights of these planes showed that the searchlights fulfilled the requirements of identification. Moreover, controls for directing the beam, independent of the maneuvers of the airplane, made visual attacks possible which greatly increased the probabilities of success.

In 1942, the Bureau of Aeronautics of the Navy began the development of aircraft searchlights specifically designed for night submarine attacks and requested the assistance of the NBS in the undertaking. Intensity measurements of incandescent, mercury-arc, and carbon-arc sources in conjunction with various reflectors were made on the Bureau's 900-foot photometric range. These measurements, and the results obtained by flight tests soon showed that only carbon-arc sources provided the required intensities. Concentrating on carbon-arcs, measurements were made of striking times and currents, operating currents, beam intensities and beam widths, employing various commercial arcs using high and low intensity carbons with reflectors of different diameters, focal lengths and degrees of precision.

Numerous comparative performance demonstrations of production models, manufacturers' prototypes and experimental models, and source and reflector combinations assembled at NBS, were made at night from the roof of the Bureau's East Building. The National Cathedral was used as the target, the range being 0.8 mile. Navy personnel and manufacturers' representatives attended most of the demonstrations to observe the performance of the various assemblies.

Candlepower measurements showed that some of the better reflectors made by "dropping" flat plate glass into a parabolic form were as good as ground and polished reflectors. A photometric method was devised for determining rapidly by a single reading of a range of 75 to 100 feet the performance that a reflector would give in a searchlight. The method was used in acceptance testing, at the manufacturer's plant, of over 100 reflectors purchased on Navy contracts.

As a result of this work aircraft searchlights were secured with less than 10 percent of the installed weight, using less than 20 percent of the electrical power and giving superior performance in most respects to those first used.
Instrument Lighting

Formation flying in hostile areas at night is possible by equipping planes with lights visible to the rear but of so low an intensity that they cannot be seen beyond a few hundred feet. Even the dimmest instrument reflections in the windshield of a plane interfere markedly with the pilot's seeing the low-intensity formation light on the plane ahead.

Early in the war, much additional data were obtained by many agencies proving that red lighting of objects requiring close attention was most advantageous when the observer needs to maintain a maximum of dark adaptation for seeing other objects. Recognizing this fact, the Bureau of Aeronautics prescribed red instrument and cockpit lighting in all Navy planes. While flood lighting of the instrument panel produces a desirable uniform brightness of the instrument markings and pointers it cannot be used because it gives rise to reflections from within the cockpit that can be picked up by an enemy airplane.

The indirect system of instrument lighting which the NBS had been developing was prescribed for all new Navy planes in Specification NAVAER SR-127 dated November 13, 1943. Several months before the specification was issued, Navy night-fighter planes were being produced with this system installed.

In this system one or two lamps for illuminating each instrument are located between the instrument mounting panel and a front cover panel. Holes are cut in the front panel for viewing the instruments. The lamps are mounted in small sockets which provide red transparent plastic caps surrounding each lamp bulb. All upward directed light is intercepted and absorbed by baffles. All downward light not incident on the instruments is absorbed in light wells.

Although separate lamps cannot give the optimum uniformity of illumination that is desired, the system is highly satisfactory from the standpoint of security and the preservation of the pilot's dark adaptation. The use of downward directed light provides a minimum of reflections in the windshield and other cockpit enclosure surfaces.

Light Source for Night Photography

In 1943, the Bureau of Aeronautics requested the assistance of the Bureau of Standards in the development and testing of accessory aircraft equipment for night photography. Since the equipment was to use standard aerial cameras, the problem was limited to the light source, its power supply and synchronization with the camera shutter.

The purpose of the equipment was to record, by overlapping photographs, the results of night bombing or depth-charge attacks on submarines and vessels made at altitudes less than 400 feet. Computations showed that such operations required photographs at the rate of 1 to 5 per second and that the light source must have a flash duration appreciably less than 0.001 second since the shutter mechanism was incapable of "stopping" the motion involved. A flash-tube source operated by capacitor discharge was the only practical setup meeting these requirements.

Photoelectric equipment was devised and constructed by an NBS group headed by T. J. Projector for measuring the light-time output of light flashes as short as a few microseconds. Measurements made on flash tubes energized by different capacitors charged to various voltages showed that for any given flash tube the integrated light output was roughly proportional to the electrical energy (1/2 CV²) stored in the capacitors. However, voltage insulation of capacitors and self-ignition of flash tubes above certain voltages limited the extent to which production design could use high voltages to save weight and space.

Reflectors for use with the relatively large flash-tube sources were studied. A neon lamp was designed which duplicated the source dimensions of the flash tube adopted for the commercial production; and candlepower distributions with various reflectors were obtained. The two reflectors showing optimum performance were further tested by graphing indoor and outdoor subjects, using a flash tube at various positions of focus. Assistance was given in the preparation of instructions for installation and operation which accompanied the production units to the theaters of operation.
Aircraft Carrier Lights

Two types of lights on an aircraft carrier make it possible for an aircraft to land at night. One of these is the "homing" light at masthead, visible to aircraft approaching from any point of the compass; the second is the landing-area light by which markings on the flight deck are made visible. An accurate directional control of light flux from these units is mandatory to prevent them from being spotted by hostile submarines. The "homing" light must be visible at the low altitudes from which landing aircraft approach but not from periscope level. The landing-area light must not protrude from the flight deck more than a few inches so that the plane can run over it without injury; it must light the landing area, but no light should reach any portion of the sea itself. The details of the landing-area light were worked out by the Navy from rough drawings by two members of the NBS staff, and the "homing" light design was modified according to their suggestions.

Seadrome Buoy Lights

To assure the safe landing of Naval seaplanes on water at night, buoy lights are necessary. Those available at the outbreak of the war were unsatisfactory both as to visual range and reliability. An extensive series of tests were carried out at the request of the Bureau of Aeronautics, which resulted in the development of lights of approximately 4 times the candlepower and satisfactory reliability. These buoy lights operate by the use of batteries and the operation period for the present design is somewhat greater per battery than was previously obtained.

Searchlight Reflectors for Warships

Searchlight reflectors for warships were very scarce during the first years of the war, not only because of the rapid expansion of the fleet, but also because of the rigid requirements for Naval searchlights. The recoil from heavy-caliber gunfire would shatter a reflector made of silver-plated glass, and would knock out of shape a reflector of silver-plated copper. Salt spray and high humidity rapidly corrode reflectors satisfactory for many land uses. Encouraged by the success obtained by J. R. Cain in corrosion protection of silver-plated reflectors in airplane landing lights, the Bureau of Ships financed a search at the NBS for a superior substitute for stellite reflectors, stellite at that time being very scarce. The U. S. Rubber Company cooperated in the investigation by attacking the problem of forming iron reflectors 25 inches in diameter by electrodeposition against a parabolic form. The Chrysler Corporation cooperated at the suggestion of M. K. Laufer by attacking the problem of "superfinishing" stellite blanks as a new source of supply of stellite mirrors.

Optical and photometric methods of evaluating the precision of such reflectors were devised by the Bureau and applied to the experimental reflectors in the various stages of development. Studies and tests were made of lacquers for silver-plated reflectors that might withstand the corrosive action of the carbon arc and the corrosion associated with sea operations. Although usable silver-plated reflectors were eventually produced, and lacquers and lacquering techniques found that were applicable to small flat mirrors, it was the successful superfinishing of stellite blanks that broke the bottle-neck on searchlight mirrors. Aroused by this evidence of the Navy's urgent need of reflectors, the original producer of stellite mirrors greatly expanded his production facilities. The resulting output plus the superfinished units eventually caught up with the Navy's increased requirements.

Signaling Mirrors

Early war experiences, particularly the Rickenbacker search and rescue, showed a need for better survival equipment for U. S. air and sea craft. A group of men working on the problem at the direction of the Joint Chiefs of Staff approached the National Bureau of Standards with a request for help in developing heliographic signaling mirrors. They were confident that mirrors for reflecting sunlight were potentially effective signaling devices for life rafts and boats. They desired a practical means for aiming reflected flashes of sunlight at potential
rescue craft, and data on suitable mirror materials and sizes.

A day or two after the receipt of this request, in the fall of 1942, L. L. Young, then a member of the NBS staff, discovered the rearsight method of aiming mirror flashes and proved it to be practical. The rearsight signaling mirror reflects from both its front and rear surfaces immediately around a sighting hole. A signaler operates this mirror by rotating it till a spot of sunlight is seen to be reflected in the rear mirror in a direction opposite to the desired direction of reflection from the front of the mirror.

Young prepared the first specification for the rearsight-type signaling mirror. Included in this specification were data obtained from tests conducted by him, data on resistance to salt spray corrosion suggested by W. Blum and L. Waldron of the NBS staff, and data suggested by the General Electric Co., which undertook the manufacture of these mirrors. Well over 1,000,000 rearsight-type signaling mirrors were produced for the U. S. armed and transport services during the war.

About a year later, R. S. Hunter, who was assigned the signaling mirror development when Young left the Bureau, examined several suggestions which had been submitted to the National Inventors Council. One of these, submitted by C. H. Learned of Carmel, California, suggested an ingenious aiming mechanism using retro-reflectors of the type employed in night-visible traffic signs. From this suggestion, Hunter designed two retro-reflector-type emergency signaling mirrors. A survivor has merely to hold his eye at the viewing window of one of these improved mirrors and he sees in front of him a red spot of light which shows the direction taken by the mirror-reflected flashes. It is a simple matter for a survivor to turn this mirror till the red spot is superimposed on any passing search craft.

Specifications for this improved type of mirror were prepared, but only about 150,000 were produced before the end of hostilities. Practically all the testing of the retro-reflector type mirrors and much of the testing of the rearsight type mirrors were conducted for the Government purchasing agencies by the National Bureau of Standards, about 1,300 signaling mirrors being thus examined.

Air Patrol Detection of Submarines

When an airplane is sent to patrol a sea area to detect enemy submarines under the surface, the observer watches a relatively small portion of the sea which is commonly supposed to be most favorable to success. At the request of the Bureau of Ships the simple optical theory of this viewing situation was worked out for horizontal and vertical surfaces of various reflectances submerged in a sea of varying roughness with the sun at various altitudes. It was found that the conventional tactics offer a reasonable chance of success over a glassy sea until the altitude of the sun falls below 11°. Presence of waves raises this angle unless the waves are smooth and favorably oriented in which case the critical angle falls to 4°. This study indicated that under some circumstances viewing near the vertical would be more advantageous than the conventional search procedure, and it corroborated camouflage measures and deception tactics used by our own submarines.

Colored Signal Lights

A smooth landing operation on a hostile beach requires that an advance party be landed, which by means of colored signal lights directs the following shoreward traffic. At the request of the Bureau of Ships, the illuminations required at the observer's eye to yield distinguishable point-source signals of red, green and incandescent-lamp light were determined in the laboratory. It was found that a lamp producing an illumination of 4 sea-mile candles, without a filter, at the eye of the observer yields, when filtered, colored signals more than 90 percent of which are distinguishable. Full-scale tests over water corroborated this laboratory result, and signaling equipment designed on this basis was used throughout most of the South Pacific campaign.

Covers for Life-Presever Lights

At the outbreak of the war, life-preservers issued by the Navy were equipped with small
battery-operated lights with red plastic covers to assist rescuers in locating personnel floating in the water. The red color was used as a distinction from the clear-bulb incandescent lamps on life-boats and life-rafts to prevent survivors from wasting energy swimming toward each other. This red color, however, reduced considerably the chance of a rescuer locating the survivor because a faint red light must be looked at head-on if it is to be seen. At the request of the Coast Guard for assistance in choosing a new color, purple covers were recommended by E. B. Judd. Dyes suitable for the plastic cover were incorporated in a plastic film; the spectral charateristics were measured; and a laboratory demonstration was set up showing that the close range color was a red not much different from that originally used. However, the short-wave energy transmitted by the film is visible to the periphery of the eye and the chance of the light with a purple cover being seen at long range approaches that of a light with a clear cover. Procurement of purple covers for a full-scale test was under way at the end of the war.

Illuminated Gun Sights

The sights show the gunner the target field on which is superimposed an illuminated reticle. In routine testing of an early type of gun sight at the National Bureau of Standards it was noticed that the reticle was highly illuminated near the center of the field, and scarcely at all near the edges. By substituting a flashed opal glass for two frosted glasses at a cost of approximately 2 cents per unit, it was found possible to raise the illumination of the reticle near the edges of the field by a factor of 10. This substitution was adopted by the Navy Department.

Color Standards

Standards for Airplane and Airport Lights

Lights of various colors control the complicated flow of air traffic in wartime. In a night-training flight, the planes of each formation assemble after the take-off guided by formation lights of distinctive color visible to the rear of each plane for a short range. Collisions with other aircraft are avoided because each plane carries position lights of longer range, red on the left wing-tip, green on the right. Landing at an airport is made possible because the approachway and runway are marked by lights of distinctive color. Collisions with other aircraft while taxiing are prevented by a distinctive tail-light in alternating colors. And finally, the delicate task of landing on the carrier at night is made possible by the plane's approach light which has a triple lens, red on top and green on the bottom separated by a thin strip of yellow. To the flight-deck officer this light appears red, green or yellow depending upon whether the plane is headed too low, too high, or just right. The smooth flow of air traffic thus depends upon using the right color at the right time.

At the request of the Bureau of Aeronautics, the Army Air Forces, and the Civil Aeronautics Administration, the NBS carried out studies regarding choice of colors and candlepowers for these lights. The design of the carrier-approach light was initiated at the Bureau as well as the procurement specification for glass and plastic ware producing these colors. Over 300 glass standards for applying this specification were procured, tested and certified by the Bureau for use in the inspection of glass and plastic ware by Army, Navy and CAA inspectors. Three types of visual comparator for carrying out these inspections for various types of cover were designed before the war. These comparators, colored glass standards, and detailed specifications have helped to provide the air forces, civil and military, with reliable and practical guides in air navigation.

Standards for Calcite

Calcite crystals were extensively used during the war not only for optical instruments requiring very clear crystals, but also in gun sights for producing a circle in the field of view whose angular size is not dependent upon the distance between the gunner's eye and the eyepiece. Calcite may be used in gun sights even though too yellow for use in precision optical instruments. At the request of the War Production Board,
OPTICS, COLOR, LIGHT

six basic calcite crystals were measured in
fundamental colorimetric terms to serve as
color standards in sorting the available
supply of calcite crystals.

Inspection of Textiles

In providing uniforms within a few months
for an Army of eight million men, nearly all
of the textile mills of the country were put
to work. Strict conformity to color stand-
ards had to be maintained in spite of a wide
variety of dyes used by the mills, and the
bulk of the inspections were carried out at
the Philadelphia Quartermaster Depot where
as many as 2,000 color inspections were made
in a single day. Since the decision to ac-
cept or reject was based entirely upon the
judgment of the inspectors and depended
somewhat on the quality of daylight used,
the smooth flow of textile materials was in-
terrupted frequently by complaints of manu-
facturers that their goods had been wrongly
rejected as off shade. At the request of the
Commanding General, PQD, twenty-five of
the color standards were fundamentally evaluated
at the NBS by means of the spectrophotometer.
A study was made of 40 accepted samples and
40 rejected samples by visual and photo-
electric colorimetry, and it was found that a
fundamental criterion of acceptability could be written which accorded exactly with
80 percent of the previous decisions of the
inspectors and with no large discrepancies
among the remaining 20 percent. This crite-
ron was based on the NBS unit of color dif-
ference and could be applied by means of the
Hunter multipurpose reflectometer. At the
conclusion of this work a reflectometer was
purchased by the PQD and used for disputed
cases in the inspection of textiles.

Color Specification

To equip an army of eight million men re-
quires the procurement of thousands of dup-
lcates of hundreds of items of equipment, a
surprising number of which must satisfy color
requirements, which must in turn be made in-
telligible to the prime contractor and his
many subcontractors. The American Standards
Association undertook to provide a practical
and fundamental method of specifying color
to speed up this procurement. At the sug-
gestion of the General Electric Company and
the Interchemical Corporation, 4 correlated
methods of color specification used by the
National Bureau of Standards and by some
portions of industry were used to form Amer-
ican War Standard ASA-244-1942.

Lamps

The inspection and life-testing of lamps
purchased by the Government are functions of
the National Bureau of Standards in peace as
well as war. Before 1941, Government pur-
chases amounted to approximately 8,000,000
lamps per year. During the 4-year period
September 1, 1941, to August 31, 1945, over
600,000,000 lamps were purchased by the Gov-
ernment, an average of 125,000,000 lamps per
year, or 15 times normal peace time purchases.
It is estimated that well over 90 percent of the
lamps purchased by the Government during
the war were supplied to the Army and Navy.
Many of them were used in places where their
satisfactory operation was critically im-
portant. The personnel of the Bureau made
continuous inspections and tests to ascertain
that these lamps complied with the applica-
ble specifications. In addition, special
tests were conducted for the Navy in the
course of the development of lamps for spe-
cific applications; for example, vibration
tests of bomb-sight lamps resulted in the
development of lamps which could withstand
the rigors of this service.

Intensity, Flux, Color

Lamp standards of candlepower and color
temperature were in abnormal demand during
the war. An important use of such standards
is the testing of photocells used by the
millions in modern mechanized warfare. Some
lamp standards were used in the establish-
ment of visual tests whereby the Navy and
War Departments were able to select person-
nel for assignments requiring unusual visual
abilities. Many went to war agencies for
purposes not yet disclosed. About 1,400
lamps and lighting devices were calibrated
during the war.
Luminescent Materials

Luminescent materials to form symbols and signs marking important controls and exits were used by the Army, Navy, Coast Guard and Maritime Commission, and also in the form of tape. Markings were required on all vessels entering the combat zone. The phosphorescent materials which absorbed energy from natural daylight and artificial light, and which glowed for as long as 24 hours after activation ceased were the most commonly employed. Fluorescent materials excited by ultraviolet sources were used for charts and maps by the Army and to a limited extent for marking exits and controls. The measurement of such materials required a different technique than that usually employed in photometry, and a photometer was designed and used at the NBS for their measurement. During the course of the war about 5,600 specimens of luminescent materials were measured, and assistance was given the various procurement offices in writing specifications for their purchase. The high requirements set in these specifications resulted in such improvements that samples submitted near the end of the war were 10-fold brighter than those first tested.

To make military maps yield their information quickly and without confusion requires close control of the colors of the inks used. The features of the terrain must be indicated clearly by suitably contrasting colors and the various colors must be controlled so that the respective meanings of the colors will be valid for all maps. At the request of the Army Map Service, 63 secondary standards for ink color were measured in fundamental colorimetric terms as an aid in the printing of maps.

The reading of maps at night was hazardous during the war because the light might be seen by the enemy. To reduce this hazard extensive use of maps printed on fluorescent paper was made by the War Department. These maps are read by ultraviolet energy which itself is invisible. At the request of the Army Map Service procurement requirements of brightness and chromaticity were developed for fluorescent map papers.
12. High Polymers

Organic materials assumed vast importance during the war. These materials—rubber, plastics, textiles, leathers, and paper—consist of chainlike molecules of very large size, and considerable advances in research have been made in recent years as a result of the growth of the relatively new science of high polymers. Extensive work was done by the Bureau in this field: the rubber program, in particular, was significant, because this key material—no longer available as a natural product—had to be synthesized.

Rubber

The development of a huge new industry for the production of synthetic rubber was one of the outstanding national accomplishments during World War II. Beginning long before Pearl Harbor, the Bureau had some part to play in a great many different phases of the program. Following a visit by L. A. Wood and N. F. Bekkedahl of the Rubber Section to the major German synthetic rubber research laboratory at Leverkusen in 1935, a survey of the published literature led to the issuance of Bureau Circular C427: Synthetic Rubbers—A review of their Compositions, Properties, and Uses. This appeared in June 1940, the month when the fall of France called into question the security of the Far Eastern supply of natural rubber. The circular had a wide distribution and was reprinted in full by one of the Senate investigating committees two years later.

In August 1942, A. T. McPherson and L. A. Wood of the Bureau staff were called on by the President's Rubber Survey Committee (Messrs. Baruch, Compton, and Comant) to investigate the possibilities of the manufacture of Thiokol as an interim material for retreading tires. A program for the manufacture of Thiokol was recommended by the committee and authorized later, but was finally abandoned when the supply of reclaimed rubber proved to be ample for retreading.

Early in 1943, the Office of the Rubber Director asked the Bureau to expand its work and to assist the Rubber Reserve Company in the standardization of the quality of the synthetic rubber. A. T. McPherson of the NBS staff was made a member of the Committee on Specifications for Synthetic Rubbers and Chairman of its Subcommittee on Test Methods. The staff was then augmented and the chemical laboratory at 203 Bryant Street, N. W., was rented from the District of Columbia to furnish the additional space required for chemical analyses. Since then, more than 50 extensive reports on this work have been written and distributed.

The Bureau played a considerable part in developing a number of the tests now being used in the synthetic rubber plants. Among them may be mentioned the use of the refractive index as a method for determining the styrene content of the GR-S copolymer, and the determination of freezing points as a method of measuring the purity of styrene, butadiene, and other monomers. Many improvements were made in the design and use of the Mooney viscometer, one of the most important instruments used in the production control of synthetic rubber.

The densities of all the common commercial varieties of synthetic rubber were measured as well as the specific heats and thermodynamic measurements of GR-S synthetic rubber. A typical project of this type was the determination of the heat of polymerization of styrene. Measurements of the heat of combustion of liquid styrene and solid polystyrene were made by means of a bomb calorimeter, and the results were used to calculate the heat of polymerization of styrene. Two samples of polystyrene of different degrees of polymerization were used. The values obtained for the heat of combustion of the two samples of polystyrene are the same within experimental error.

A reference method for determining the purity of 1,3-butadiene was prepared for inclusion in the Rubber Reserve Company's book on specifications, and determinations were made of the purity of monthly cross-check samples of product butadiene and of special samples of butadiene and other hydrocarbons. The determination of the purity of these
substances by measurement of their freezing points serves to give an absolute measure of the purity of given samples and also as a control for the more rapid routine methods of analysis.

Values were obtained for the heats of combustion of the hydrocarbons used in the production of synthetic rubber. The collection, analysis and correlation of data on the properties of hydrocarbons described under the aviation fuels project, was also useful to the engineers, technical men and scientists concerned with the production of synthetic rubber.

Many samples of soap used in the manufacture of synthetic rubber were analyzed and specifications for such soaps were formulated. The molecular weight distribution in some 20 samples of DD mercapto modifier used in the synthetic rubber industry was determined and was used by the industry to correlate the behavior of different lots of the material with their composition.

As successive synthetic rubber plants came into operation, cross-tests were made with the Bureau each month until the Rubber Reserve Company was satisfied that plant testing was being conducted properly. Since then a series of standard control polymers have been set up for periods of 3 months to 6 months at a time. The Bureau made extensive measurements on these standard rubbers, and the Bureau values were taken as a basis for rating the plants by the Rubber Reserve with respect to accuracy and precision of results.

The fact that 15 Government-owned plants, scattered throughout the country, were required to produce rubber to meet identical specifications required more uniformity of test procedures than had heretofore been necessary. The NBS took a leading part in standardizing these procedures in both the physical and chemical fields in order that results from different laboratories would be truly comparative. As a result of a great number of cross-tests and intercomparisons between laboratories the accuracy and precision of rubber testing in this country have been notably improved.

At the request of the Brazilian Government a member of the NBS Rubber section was loaned to the Instituto Agronomico do Norte at Belem do Para, near the mouth of the Amazon River, for the purpose of organizing its Rubber Laboratory. This cooperative program was arranged through the Department of State under Public Law No. 63 (76th Congress). The first tour of duty was 2 years—from November 1942, to November 1944. During this time Norman Bekkedahl supervised the installation of the apparatus and machinery of the laboratory and trained a staff of Brazilian scientists in the scientific testing and grading of raw natural rubber. A second visit was made during June and July, 1946, for the purpose of checking up on the progress of the Rubber laboratory and to initiate new research. The NBS Rubber section has continued to act in advisory capacity to this Rubber Laboratory.

In 1942 the average Brazilian had no idea of the situation existing in the United States in regard to the relationship between natural and synthetic rubber, either from the economic or the technical viewpoints. There was no literature to be found on the subject in the Portuguese language. Therefore a bulletin of the I.A.N. was prepared in Portuguese dealing with these subjects and entitled "Borracha Natural e Borracha Sintética" (Natural and Synthetic Rubber). For the convenience of the young scientists interested in rubber technology, a comprehensive article was written on "Mistura Industrial e Análise de Borracha para Fins Específicos" (Industrial Compounding and Analysis of Rubber for Special Purposes).

In the laboratory of the I.A.N. studies were made of various methods of coagulating rubber from latex. A method was developed for the processing of latex of Hevea brasiliensis into rubber, which is described in the February 1944, issue of India Rubber World. This method, because of its slowness, is not one recommended for plantation procedure, where the volume of production is great and where good technical assistance and chemical control is available, but it is recommended for the thousands of rubber producers of the Amazon Valley who have but a few trees at their disposal and who have no scientific or technical knowledge. This method can produce natural rubber of the best grade.
Evaluation of Wild Rubber

When the importation of rubber was cut off from the Far East, one of the emergency measures taken by the U.S. Government was the purchase of all possible wild crude rubber from South and Central American and Africa, no matter what the quality or type. The Bureau set up a laboratory for testing and grading these rubbers and a system of evaluation was established by which all types of rubber were placed in one of four classes: I(excellent); II(good); III(fair); or IV(poor). During the war-period over 1,000 samples were thus graded so that they could be put in channels for most efficient utilization.

Pneumatic Tires

In the early months of the war, when interim tires were of vital importance to the nation, 3 types of road tests were made at the Bureau on early synthetic rubber tires, and on tires made of 100% reclaimed natural rubber. The results were reported to the Secretary of Commerce and later the data with some additions was issued as a Bureau publication.

When the Office of Rubber Director was established the Bureau cooperated with that agency in making laboratory tests of production tires—principally those made by the smaller manufacturers who did not have adequate testing facilities. The results served the dual purpose of aiding the small manufacturer and at the same time screening out products that were not sufficiently developed to warrant road test by the War Department.

When the first synthetic truck tires were made it became evident that the temperature developed in them would, in most cases, be greater than in natural rubber tires. A system of measuring temperature in various parts of a tire was developed, using a series of thermocouples which could quickly be inserted in prepared locations. Temperature measurements have been useful in predicting the performance of different types of tires and in indicating the effects of increasing loads or speeds.

Substitutes in Rubber Products

With the emergency shift from natural to a synthetic rubber, the Bureau aided in determining the most suitable types of synthetic rubber to be used and in testing proposed substitutions. One of the questions most frequently asked concerned the performance of the substitute materials at low and high temperatures. Bureau work on the thermodynamics of rubber before the war proved of immense practical value in interpreting the rather complicated action of many rubbers at low temperatures and aided in the recommendation of suitable performance tests for finished products. As examples of the wide variety of products for which methods of test were devised, mention is made of rubber parts for land mines, cords for barrage balloons, pontoon fabrics, crash pads for tanks, gaskets for innumerable varieties of containers, soles, heels, milking machine inflations, and jar rings for home canning.

Research on the electrical and mechanical behavior of synthetic rubber compounds led to the development of a satisfactory synthetic rubber insulation from GR-S and gilsonite.

Throughout the war the NBS Rubber section engaged in the experimental production of rubber articles and rubber parts for many different projects within the Bureau and for other government agencies, such as the Navy's David Taylor Model Basin, the Washington Navy Yard, the Johns Hopkins University Applied Physics Research Laboratory and the George Washington University Ballistics Laboratory. The ultimate uses of many of these parts was for secret projects and in many cases were not known to the Bureau.

Evaluation of Sources of Rubber

The national emergency brought forward many suggestions regarding new sources of rubber supply and new methods of making rubber and rubber-like materials. A great many of these proposals were referred to the Bureau for evaluation. Two general questions were asked: (1) Is the material under consideration rubber or sufficiently like rubber
to serve some of the same purposes? (2) Is the proposed method of production practical?

The first question could usually be answered readily by a simple inspection of a specimen of the material, but in order to establish a definite standard for rubber-like performance the following requirements were set up: (1) The specimen should be capable of being stretched to double its length and should forcibly retract on release; (2) it should withstand the action of water without disintegrating and without swelling or softening excessively; (3) it should retain its flexibility on drying; (4) it should not become hard or brittle at freezing temperatures. The relation of these requirements to serviceability was self-evident and the tests were simply and easily made.

The majority of the proposed substitutes for rubber that were offered failed to meet the requirements. Most of them, in fact, represented simply the rediscovery, in one way or another, of the elastic properties of glue or of factice. Glue, gelatine, and certain other proteins can readily be prepared in the form of gels which are resilient and have a somewhat rubber-like feel. Compositions made from glue, glycerine, and a tanning agent have long been used for printers' rolls and for hectograph pads, but they are not capable of replacing rubber in other types of applications. Factice likewise has properties resembling rubber, but not to a degree that would render it generally useful as a substitute for rubber. It is made by the reaction of vegetable oils with sulphur or sulphur chloride. Although it has been known to industry for over 100 years, the public is familiar with it only as "art gum." Many inventors, in stirring up mixtures of all sorts of common materials, often chanced to use glue or gelatine as an ingredient, and when the mixture set to a tough gel they attributed the resilience to ingredients other than the glue or gelatine. Other inventors, knowing that rubber was commonly vulcanised with sulphur, heated mixtures of materials including vegetable oils or fats with sulphur and obtained a semblance of resilience and elasticity which they failed to recognize as due to the production of factice. None of the products offered had properties equal to those of the commercial articles made from glue and factice composition.

A smaller number of the products that were offered were very different in character in that they were clearly recognizable as rubber, and easily met the above-mentioned standards for rubber-like performance. In evaluating these products, the problem as viewed by the Bureau was to make an estimate of the practicability of producing them in the manner claimed. The inventors or promoters often had a different point of view. They felt that if the NBS would only test the sample offered and show that it had useful properties it would at once be in order for the Government to finance the erection of a full-scale factory without knowledge of the process to be employed.

To safeguard the interests of the Government, the Bureau required a full disclosure before it would investigate a process, and took the position that the first test to be made was the independent repetition of the process. The inventor was advised to protect his own interests by filing a patent application before making the disclosure. The disclosures in many instances revealed that rubber, either natural or synthetic, had been used to make the sample. The inventor usually regarded the rubber thus employed as "seed" but had not taken pains to determine accurately the relation between the "seed" and the product. When these processes were repeated quantitatively the actual yield of rubber was identical with the amount of "seed" used. In a few instances the inventors had employed rubber cement or rubber latex as an ingredient without knowing that they contained rubber.

In other cases the rubber had been "extended" by the incorporation of fillers, asphalts, greases, oils, and other ingredients. This is regularly done in all rubber goods manufacture so the processes were not regarded as methods of making rubber, but rather as means of compounding it.

A few of the processes submitted for consideration represented the independent rediscovery of types of synthetic rubber that
were already in production. This was particularly true of Thikol which can be made easily by treating various commercially available dichlorides with sodium polysulphide.

The NBS was repeatedly requested to test specimens of rubber said to have been made by secret processes. The suggestion that the inventor apply for a patent so that the process could be disclosed usually brought the counter proposal that members of the Bureau staff witness a demonstration in which rubber was made in a locked container from ingredients the composition of which was not disclosed. It was pointed out that no conclusions could be drawn from such a demonstration, and furthermore, that it would not be possible to keep the process secret if it should be operated on a commercial scale. Some of the inventors and promoters of secret processes stated that they would engage in production without government backing, but no rubber was put on the market.

Thus, the net result was that no new processes were found for making rubber. The work, however, served the useful purpose of assuring Government officials responsible for the national rubber program that no important new discoveries were being overlooked.

Plastics

The growth in importance of plastics as a new material of commerce was recognized in 1935 by the formation of the Organic Plastics section under G. H. Kline. The functions of the new section included studies of relationships between molecular structure and properties of synthetic resins, evaluation of commercially available plastics with respect to mechanical, thermal, optical, chemical, and permanence properties, and investigation of the interrelationships between film-forming plastics, plasticizers and solvents in order to provide improved protective coatings, films and adhesives.

The nature of the Bureau's activities on plastics changed markedly when we entered World War II. It became a proving ground for plastics in all types of military equipment. The facilities of the section were utilized in the development and testing of plastic products by the various war agencies, including the War and Navy Departments, the Maritime Commission, Office of Civilian Defense, and the War Production Board. Many of the items made of plastics became standard stores in the various branches of the service. Typical of the diversified applications of plastics materials which were worked on during the war years are the following: aircraft light coverings, baking-type resinous coatings for protection of steel hardware, bayonet handles, binocular coverings and housings, bugles, canteens, card holders, clock housings, compass dials, dopes for airplane fabric, films for gun covers, raincoats, packaging food, foot tubes, fuze parts, gas capsules, goggles, insignia, helmet liners, insect screening, mess trays, shaving brushes, tableware, transparent plastics for aircraft enclosures and whistles.

Molded Products

The helmet used by the armed forces during the war consisted of a single-size outer steel shell which fitted snugly over a plastic helmet. The light plastic helmet afforded satisfactory protection to the wearer except in actual combat when the steel shell was slipped over the plastic. The first liner was made of paper pulp covered with fabric. This liner was not durable, did not retain its shape after wetting and drying sufficiently to fit the steel shell, and had a low resistance to impact. The Office of the Quartermaster General asked the NBS in 1941 to assist in developing a satisfactory plastic helmet liner. Work was immediately started to develop suitable test methods and to evaluate experimental liners made from several kinds of plastics in several types of construction. This work resulted in a helmet liner made of a cotton-fabric laminated phenolic plastic. The first satisfactory liner put in production was molded at a low pressure (125 lb/in²); this was one of the first large scale applications of the low-pressure molding technique. Investigations to assist the Army contractors in developing liners to meet the initial Army requirements and to develop a product which
would meet more rigid requirements were continued through 1944.

In 1943, the Office of the Quartermaster General requested the NBS to investigate test methods for and to evaluate the mechanical, thermal, and permanence properties of experimental and production samples of Doron, a glass-fabric laminated plastic body armor. Because of the unusual characteristics of this material, the standard test methods for plastics were not satisfactory in some cases. The properties investigated included machinability, density, resin content, indentation hardness, water absorption, tensile strength, compressive strength, flexural strength and modulus of elasticity, peel strength, tensile shear strength, torsional shear strength, compressive shear strength, impact strength, vibration fatigue strength, heat distortion, resistance to accelerated weathering, and resistance to exposure to cycles of high and low temperatures and high and low relative humidities. The production of Doron had reached a high rate when the war ended and was being used in personal armor in the Pacific area. It was found to be superior to an equal weight of steel or metal armor in the ability to stop flak, revolver bullets and slow speed bullets.

In 1942, the Joint Optics Committee of the Army-Navy Munitions Board called a meeting of representatives of the Army and Navy to discuss possible replacement materials for the aluminum used in binocular bodies, aluminum being at that time among the more critical materials. The Materials Officer of the Naval Observatory recommended to the committee that binocular bodies be fabricated from a plastic material. The NBS was requested to assist in the selection of a suitable plastic for this purpose. Investigation of the dimensional stability and impact strength of various materials revealed that a thermosetting phenolic molding compound containing a long-fiber asbestos filler would be satisfactory for the binocular housings. Another important requirement was that the metal inserts used to secure the optical components and to provide additional structural strength should possess a coefficient of thermal expansion closely approximating that of the plastic. This matching of the coefficients of thermal expansion is necessary to maintain collimation of the optical systems over the temperature range encountered in service and to prevent cracking or separation of the plastic material due to stresses induced by temperature changes. An aluminum-silicon alloy, which could also be die cast to close dimensional tolerances, was found to be most suitable.

Evaluation tests performed on the 6 x 42 plastic binocular indicated that it satisfactorily fulfilled all requirements for a general-purpose service binocular. The extreme resistance of the instrument to fungus growth, corrosion and moisture penetration, as well as its rugged construction and fixed adjustment features, makes the plastic binocular exceptionally well suited to specialized service such as night, tropical, amphibious, infiltration and submarine use.

**Aircraft Applications**

Depressions occur at rivets, welds, and junctions of metal plates on metal aircraft. Unless these depressions are properly filled, the aerodynamic efficiency of the airplane at high speeds is appreciably reduced. Materials for this purpose have been called rivet and depression fillers, fairing compositions and aerodynamic smoothing compounds. A critical problem involved in their use is the maintenance of adequate adhesion to the metal under the extremes of temperature, weathering and vibration encountered in service. An investigation revealed that important factors in obtaining satisfactory performance are low moisture absorption, a softening temperature no higher than the temperature of application and a coefficient of thermal expansion at low temperatures equal to that of the metal. Tests were developed to evaluate fairing compositions made with experimental mixtures of various plastics, fillers and solvents. A formula was worked out to calculate the necessary proportions of resin and filler to produce a fairing composition having a desired coefficient of thermal expansion. A compound which adheres satisfactorily to aluminum alloy consists of 20 parts vinyl acetate resin ATAF, 56 parts Asbestine SX, and 26 parts of zinc dust dispersed in a mixture of 2 parts ethyl ether.
and 1 part acetone to a solvent content of 20 percent.

In the construction of airplanes with pressure-sealed cabins, the problem arose of finding suitable means for mounting the glass windshields and windows. The mounting must furnish an airtight seal over a wide range of temperatures, must allow for differential thermal expansion of the windshield relative to the frame without the creation of high stresses in the glass, and must not be so flexible that the windshield deflects excessively under service conditions. To meet these requirements several mountings have been proposed in which the plastic layer of the laminated glass is extended beyond the edge of the glass, the windshield being held in place by bolts through the extended plastic edge. In order to evaluate mountings of this type, an investigation was made of several types of plastic mounting. The deflection characteristics, creep behavior, and bursting strength at various temperatures were included in this work.

The advantages of sandwich construction involving stiff dense faces separated and stabilized by a thick light core have long been known. In the aircraft industry considerable interest has been stimulated in sandwich materials by the ever-increasing difficulty of maintaining rigid contours in high-speed aircraft. This type of construction was employed for an experimental resin-bonded glass-fabric fuselage built during 1943-44 by the Army Air Forces. Balsa wood has generally been employed on aircraft as the stabilizing medium but research is currently in progress to develop more satisfactory low-density materials from plastics. Seven types of low-density materials were investigated at the Bureau. The properties studied included density, thermal conductivity, dimensional stability on exposure to extremes of temperature and relative humidity, resistance of the materials to chemicals, and flexural and compressive strengths.

Adhesives

In the construction of aircraft the attachment of component structural elements is accomplished by various means, such as riveting, bolting, welding, and in some instances by gluing. While present procedures are generally satisfactory, it is possible that, provided suitable adhesives can be found, gluing might be the most rapid and efficient method of assembly. This method is now used widely in plywood construction. The development of adhesives for bonding metal, wood, rubber and plastic parts on aircraft has been largely empirical. A better understanding of the physical and chemical forces involved in adhesion is needed for further rational improvement of bonding materials for use in aircraft construction. A research project was undertaken to obtain information on the strengths of bonds between different chemical types of adhesives and adherents. As part of this project a survey was made of our present knowledge on the nature of adhesion. This report has been in wide demand and has been characterized as "a much needed contribution for better understanding of the fundamentals of adhesion."

Failure of adhesive bonds can be attributed to boundary stress concentrations. An analysis of the causes of internal-stress concentrations in rigid adhesive layers led to the conclusion that stress concentrations can be eliminated in many cases by matching the coefficients of thermal expansion of the component parts. A stress-equilibrium formula for calculating the thermal-expansion coefficients of mixtures, involving the density, modulus of elasticity, coefficient of thermal expansion, and proportion by weight of the ingredients, was derived and reported to the National Advisory Committee for Aeronautics. The formula was applied to lead-antimony and beryllium-aluminum mixtures, phenol-formaldehyde resin and glass-fiber mixtures, and plastic plywoods. The thermal-expansion coefficients of a number of pure and reinforced plastics were reported. Bonds obtained when thermal coefficients are matched were shown to be stable over a wide temperature range.

Protective Coatings

The Office of the Quartermaster General in 1941 requested the NBS to assist them in developing test methods, evaluating commercial and experimental coatings, and writing specifications for organic resinous coatings for metals. Initially the coatings were
intended for items of hardware for uniforms, such as buckles, insignia, clips, buttons, eyelets, etc. The work was expanded as it progressed to include coatings for helmet liner fittings, water cans, food cans, gasoline cans, canteens, closures and grommets. The test methods developed included procedures for determining flexibility, adhesion, and the effects of cold water, hot water, steam, weak acids, weak alkalis, petroleum solvent, chlorine water, salt spray, accelerated weathering and abrasion. The coatings which met the requirements of the Army were baked phenolic, urea and melamine resin coatings. In addition, a rust-inhibiting primer coat, such as a deposit of metallic phosphates, was found necessary for articles made of iron and steel.

Because of the relatively low price and ready availability of toluene and aromatic petroleum naphtha, a great many commercial aircraft-coating materials (dopes, lacquers, enamels, primers) were designed around them. When the war program created a sudden large demand for toluene and related materials for use in explosives manufacture, their use in lacquers, dopes, primers, enamels and thinners had to be severely curtailed. Under this and closely related projects extensive experimental work was conducted to provide the Navy Bureau of Aeronautics and the War Production Board with the basic information on the reformulation of all coating materials and thinners thereby affected. Studies were made of physical and chemical properties such as viscosity, base, evaporation rates, blush resistance, film formation, shrinkage, flexibility, compatibility of coating ingredients, weathering durability, shelf life, corrosion resistance, hiding power and adhesion to metals and fabrics. Problems of similar type arose again and again throughout the war period as the solvent and resin supply picture changed. The accumulated data and experience permitted the formulation of satisfactory alternates to keep pace with the wartime demands.

The widespread use of glass in all types of buildings and transportation vehicles presented a critical problem in providing measures for protection against air raids. Glass splinters projected through the air by bomb explosions resulted in personnel casualties, damage to machinery, and disruption of blackout facilities in Great Britain. At the start of the war in this country many different materials and methods were proposed for treating glass to prevent scattering. The Office of Civilian Defense requested the NBS to evaluate these and submit recommendations concerning their use.

A vacuum-concussion apparatus similar to one designed in England for the same purpose was used to test glass treated with lacquers, tapes, plastic films, and adhesive-fabric combinations. The materials which gave satisfactory results as initially applied were subjected to wet-dry cyclic and heat tests to determine the aging characteristics of the antiscatter materials. Only a few materials retained the particles of glass satisfactorily in the vacuum test after subjecting the two accelerated aging tests. A report was prepared which includes a review of the experimental work and experience of the British in developing treatments for glass to prevent it from scattering when fractured by bomb explosions. In addition to its significance in protection against flying glass during air raids, the report is of interest to manufacturers concerned with general problems relating to adhesion of materials to glass.

Textiles

The clothing requirements of the men and women of the Armed Forces were as different as the varied climatic conditions of the Arctic, the tropics, the desert, the jungles, the foxhole, the stratosphere, the cramped confines of tanks and endless drifting in a life raft. Clothing had to keep water out in a driving rain and yet allow it to go through when the wearer was perspiring. It had to be light in weight, not bulky, yet strong and durable. Special fabrics were required to be fireproof, waterproof, windproof, lightproof, mildewproof, gasproof and even bulletproof. As one harassed investigator said in response to the steadily increasing performance requirements of the
Armed Services: "They want textiles that are infinitely strong and infinitely light, that give perfect protection against heat and cold and finally are digestible in case of an emergency."

The Army, Navy, Marine Corps, War Production Board, National Research Council, Board of Economic Warfare, and Office of Price Administration requested the aid of the NBS Textiles section under W. D. Appel in the development of many military fabrics and clothing. Many of these items had to meet the special requirements of a specific purpose. New methods and instruments were developed at the NBS for this purpose and technical data were provided on which to base procurement specifications. Other Government agencies also requested technical information and tests of textiles in order to maintain the quality of products or to find substitute materials where critical shortages existed. The Textile Foundation Research Associateship at the NBS likewise carried out a great amount of work for the Quartermaster Corps of the Army, which is not included in this report.

Parachute Fabric and Shroud Lines

Assurance of an adequate supply of silk for parachute fabric and shroud lines was uncertain in the event of war and therefore work on the development of substitutes for silk for parachute fabrics and shroud lines was undertaken for the Bureau of Aeronautics, Navy Department, several years before the war. In cooperation with textile manufacturers, experimental fabrics and shroudlines were made from cotton and rayon, and construction specifications for these were recommended which would provide suitable substitutes for silk. Trial parachutes were constructed and drop tests made. After the development of nylon and vinyon, shortly before the war, similar experiments were immediately carried out with them and the special handling required in weaving and finishing of nylon was worked out. In cooperation with textile plants experimental nylon fabrics were produced and drop tests were made on trial parachutes made from nylon. This cooperative undertaking was so successful that at the outbreak of the war, the nylon parachutes and shroud lines which had been developed as substitutes for silk were actually superior to silk. During the war, technical advice and assistance was given in the development of parachutes for special purposes, such as heavy cargo and bomb chutes and extremely light flare chutes and a superior nylon webbing for parachute harness.

At the outset of the war it was apparent that many million yards of cloth would be needed for parachutes for landing troops, materials and supplies. The air permeability of the parachute fabric is an important specification requirement. An improved instrument for measuring the air permeability of fabric without cutting the cloth was developed by the Textiles section which greatly facilitated the testing of parachute fabric. It also provided means for testing highly wind-resistant fabrics for clothing on the one hand, and very porous netting on the other.

Pile Fabrics for Cold Climates

The properties and performance characteristics of over 200 pile fabrics of varying construction and fiber compositions, including alpaca, mohair, wool, aralac and rayon, were investigated for use in cold weather military clothing. Most of the pile fabrics were also tested in combination with wind-resistant fabrics to find the best combinations for maximum protection.

To determine the bulk density, compressibility, and compressional resilience of a pile fabric, it was necessary to measure the thickness at various pressures ranging from 0.005 lb/in² to 1.0 lb/in². To accomplish this a new compressometer was developed. This instrument was also found useful in testing blankets and fibrous fillers for sleeping bags.

Sleeping Bags and Blankets

The large number of sleeping bags required during the war made it imperative to find suitable materials to augment the limited supply of down for fillers. Extensive tests
were undertaken for the QM to evaluate a large number of fibrous materials as possible fillers in place of the down or in combination with down. Special equipment and testing procedures were devised to test the probable performance of these filling materials. The data obtained proved to be most helpful in answering technical inquiries from the Armed Services and other agencies.

The properties of blankets were studied by H. F. Schiefer to determine how construction and fiber composition affected the warmth and serviceability of blankets, and to provide basic information for the procurement of part-wool military blankets in the event of a critical shortage of wool.

A study was also made of blanket and sheet combinations for outdoor use, for blankets alone do not give sufficient protection to one exposed directly to wind and rain or snow, as in an open lifeboat. This led to the adoption by the Maritime Commission of a blanket and water-proofed cloth combination for use in equipping all lifeboats.

An empirical equation was derived from which the thermal insulation of a textile fabric could be computed from the thickness at a pressure of 0.10 lb/in². Performance requirements were suggested which have been used as the basis of the Commercial Standard specification for hospital blankets.

Shrinkage of Fabrics

Excessive shrinkage of wool socks and knit fabrics in field laundering made these items prematurely unserviceable, taxed replacement facilities and interfered with the shipment of many other military articles. In the study of non-shrinkage treatments for these knitted fabrics it was necessary to develop new instruments and methods for the measurement of changes in the dimensions of socks and knitted fabrics, as well as a laboratory laundering procedure which would simulate the drastic laundering and felting the socks received in the field. Several devices were developed for measuring the socks under known and reproducible tension and the laundering procedure. They were used as standard equipment in the extensive research undertaken by the Office of the Quartermaster General and industry, and contributed to the successful solution of the shrinkage problem of socks.

A similar device was developed for measuring the dimensions of knitted fabrics under known and reproducible tension and provided a basis for a standard procedure in the research on knitted fabrics. These devices and procedures should be of value in the civilian knitting industries.

Rope and Cordage

Rope and cordage, essential life lines in every theater of operations, had to be strong and resistant to light, heat, weather, salt water, micro-organisms and abrasion. They had to withstand repeated flexing, repeated loading and unloading, and for some uses such as for glider tow rope and parachute shroud lines, they had to absorb high impact loads without breaking or weakening. During the war it was imperative to conserve the available supply of rope and extend it by utilizing every available substitute where the inherent qualities of manila, sisal and nylon were not absolutely necessary. Extensive research and testing on ropes made of substitute materials was carried out at the NBS. The breaking strength, elongation, ability to absorb impact loads, and the resistance to light, heat, weather, salt water, abrasion, and mildew of ropes made from a great variety of fibers and mixtures of fibers were determined. The results formed the basis for emergency procurement specifications which were prepared not only for military uses but also for civilian uses such as life lines in ship building and binder twine for the farmer. Nylon rope had a breaking strength about 50 percent greater than that of a manila rope of the same size.

The tremendous increase in cordage and rope required for military uses and the loss of a large source of supply created a very critical condition. New sources of cordage ropes had to be evaluated as substitutes. The development of machines and procedures for testing cordage fibers in small and unspun lots was undertaken by the NBS at the request of the Board of Economic Warfare, with financial assistance from the Defense Supplies Corporation. The purpose of the
invention was to provide a quick evaluation of the characteristics of experimentally grown fibers and the less-known native fibers, using fibers long employed in the manufacture of rope and cordage as a basis for comparison. It obviated the need for making large quantities of fibers into rope for testing purposes and the characteristics of fibers from a single leaf could be measured when desired.

One of the outstanding results of this investigation was the profound effect which the direction of twist in the ply relative to that in the bundle of fibers had on the resistance to abrasion of the fibers, regardless of the kind of fibers. The results and instruments developed are now being used by the Department of Agriculture, where research on cordage fiber production is being continued.

Substitute for Silk Powder Bag Cloth

Silk, long used in powder bags for large caliber guns, was a critical material during the war and it was essential that a suitable substitute be available if required. The Bureau undertook this development at the request of the Bureau of Ordnance, Navy Department, and the NDRC. The substitute had to meet the requirements inherently possessed by silk. It had to resist rough handling and deterioration by gaseous oxides of nitrogen which are slowly liberated from nitrocellulose powder. Combustion must be as complete as possible and of such character that any fragments left would rapidly cease to glow or smolder. Finally it should be resistant to deterioration at such temperatures as might occur in storage, and it should not take up moisture to the extent of becoming wet at high relative humidities.

The above characteristics of the silk fabrics used in powder bags were compared with those of substitute materials including wool, Arealac (casein), acetate, nylon, and a host of chemically-treated cotton fabrics. A rating system was devised for combining the various properties determined into a single performance index number in accordance with the relative importance of each property. From this information new formulations were prepared for chemical treatment of cotton fabrics, which were tested and their performance index numbers computed. Three formulations were found for cotton which made the treated cotton fabrics approximately equal to that of silk, one being a little superior and two being slightly inferior. In the event of a serious shortage of silk for powder bags any of these three substitutes would have performed satisfactorily.

Reference Standard Lamp

The arc lamps used for testing colorfastness of dyed textiles and for making accelerated aging tests vary greatly from one laboratory to another. In order to compare results obtained in the different laboratories, which was very essential during the war, it was necessary to develop a reference standard lamp. This is a carbon arc lamp housed in a room where air temperature and relative humidity, the line voltage and arc current are automatically controlled and recorded. The radiant output of the visible and ultraviolet regions of the spectrum is recorded by an instrument specially built for the purpose. A ten-year’s supply of carbon electrodes manufactured for the lamp from one batch of raw materials to meet very close tolerances was procured. The lamp has been adjusted to produce fading at a rate equal to that of the average of 44 lamps used in the textile industry and research laboratories. A simple method for calibrating fading lamps in “standard fading hours” has been developed, using a special blue-dyed paper.

Tropical Deterioration of Textiles

The protection of textiles from “weather,” light, heat, wetting and drying and from such micro-organisms as mildew, rot producing fungi and bacteria is a serious problem in peace as well as war, especially in the southern states and in tropical countries. The tremendous quantities of jute and cotton sand bags, camouflage nets, tentage and other textiles required by the United States and her Allies made it imperative to try to prolong the life of these materials as much as possible. The NBS installed a microbiological laboratory at the request
of the United States Army Engineers early in the war. In addition to the investigations and testing of this laboratory as described elsewhere, extensive work was done for the office of the Quartermaster General on the deterioration of tentage exposed outdoors. Rutherford and Harris showed that the hydrolytic, oxidative and biological deterioration of cellulosic textiles resulting from outdoor exposure could be distinguished. Appel, Tener and their co-workers undertook researches on the deteriorating action of copper naphthenate and other fungicides for the Joint Army, NaV, NDRC Committee on Tropical Deterioration. Because of its public as well as military importance this work is being continued.

Coated Fabrics

A part of the material of the Armed Services consisted of a variety of devices which, quite apart from vehicle tires, functioned as pneumatic or buoyant structures. These included airships, balloons, life rafts, and landing boats, and various forms of life saving equipment. From the first the NBS participated in the evaluation of the coated fabrics employed in the construction of these devices.

Examples of such work included the following: (1) Barrage balloons, initially constructed of lightly coated, black-colored neoprene balloon cloth, which underwent rapid actinic deterioration. The results of extensive tests resulted in the eventual adoption of aluminum pigmented outer coatings; (2) a critical study of the physical characteristics of fifteen different types of fabric construction specified for life rafts by the Navy resulted in the reduction of this number to three. This greatly simplified manufacture and afforded a considerable saving in the much-needed cotton cloth; (3) a comparison of the structural characteristics of cotton, rayon, and nylon as a base for coated fabrics established, through the examination of a single style of fabric, the advantages and disadvantages inherent in the three types of fiber; (4) the necessity for replacement of natural rubber led to an extensive and prolonged examination of fabrics coated with reclaimed rubber, neoprene, Thio-kol, Buna S and N, butyl rubber, and poly-vinyl resins. The problem was complicated not only by the peculiar needs of the military services but also by the manufacturing facilities, which were adapted to handle only the natural product. The eventual compromise was the neoprene sandwich-type of construction wherein the gas-impeding layer was synthetic and the outer surfaces were natural rubber mixed with reclaimed rubber; (6) a rapid and simple test was developed to determine the performance of a coated fabric under conditions of extremely low temperature.

Evaluation of Textile Materials

Many textile materials for military purposes were evaluated. Typical examples are: Cooling efficiency of desert water bags; effect of fiber composition, construction and finishing on durability of shoe laces; sun helmets and effect of treatment when exposed to rain; fillers for life jackets and substitutes for kapok; asbestos gloves and substitutes for asbestos; insulation against cold of Arctic boots, electric flying suits, parkas, gloves, and combinations of gloves; resistance to wear of jungle boots and flags; construction and finish of fabric suitable for two targets at high flying speeds; and parachute harness webbing under conditions simulating actual use. Tests were made and data furnished regarding hundreds of samples of wearing apparel to such agencies as WPA, OPA, FTC, UNRRA and BEW for purposes of specification, conservation, maintenance of quality, price classification, and procurement of suitable substitute materials. Captured enemy garments and textile products were studied in relation to what they might reveal regarding enemy resources and shortages.

Paper and Paper Products

War Map Paper

The Paper section under E. W. Scribner cooperated with the Corps of Engineers, U.S. Army, in the development of a new type of paper for war maps. This paper meets all requirements of the services far better than
any paper heretofore available, and is suitable for use under the most severe conditions of training or combat.

Commercial manufacture in quantity to meet the needs of the Armed Forces was accelerated by the Bureau staff through technical assistance to manufacturers, including the experimental study of papermaking materials and processes in the NBS paper mill. The unique properties of the paper were obtained by the use of bleached sulfate-cooked fibers of high strength and the synthetic resin, melamine-formaldehyde. In the work in the NBS paper mill it was found that this unique fiber-binding resin doubled the dry bursting and tensile strength, increased the wet strength (paper saturated with water) fivefold, and increased the dry folding endurance tenfold. Although the dry tearing resistance was reduced, the resistance of wet paper containing the resin was much greater than that of dry paper without it.

The relative resistance to handling when wet of the resin-bonded map paper and similar paper without resin was tested in the following manner. The two papers were subjected to exactly the same treatment. They were soaked in water for 24 hours, agitated gently for a few minutes, then the excess water was removed by squeezing in the hand, and the sheet gently straightened as completely as possible. The resin-bonded paper had good handling qualities while the ordinary paper came apart to such an extent as to lose its sheet characteristics.

The performance of the paper has been so satisfactory that all of our agencies making war maps have adopted it as standard, and it went to Great Britain under Lend-Lease. Maps printed on it have proved far superior to any previously used. They have greater strength and withstand treatment that would disintegrate ordinary maps. They remain serviceable even when soaked with water or oil and after being trampled in mud and subsequently washed with soap and water or gasoline.

Standards and Conservation

At the request of the War Production Board, and with the assistance of funds from OSRD, the Paper Section participated in an investigation of asphalted papers and other sheetings for use in lining shipping-cases. The investigation was made to develop improved specifications for the liners so that they would give better service in overseas shipments of supplies.

Packages in which the sheetings under test were used as case-liners were subjected to simulated service conditions at the Package Research Laboratory, Rockaway, New Jersey. The packages were put through cycles, being tumbled in a drum, dropped on a concrete floor, and bounced on a vibrator, with wetting, under both tropical and arctic conditions. They were then examined for permeation of moisture and for the condition of the liners.

Correlation of the test data of the sheetings with the simulated service trials indicated that for the most satisfactory service, the caseliner should be composed of sheets of kraft paper cemented together with asphalt, and that the important properties are: Areal weight of paper and of asphalt, wet tensile strength, stretch, and resistance to tearing and to permeation by water vapor and water. Recommended requirements for these properties were formulated.

Paper and paper products in their various forms played an extremely important part in the war. The procurement of the huge quantities used by the armed services and other agencies was a most difficult task and it was complicated by shortage of raw materials caused by their diversion to more essential uses and the necessity of substituting paper products for other more critical materials.

In order to keep the Federal Specifications for purchase of paper and paper products in line with ever-changing conditions of supply, it was necessary to make frequent changes in them. Much of the groundwork for new or revised specifications incorporating substitute materials was developed through testing of such materials in cooperation with manufacturers. Following are some of the more important developments of this kind. (1) Paper shipping sacks were extensively substituted for wood, metal and textile containers. It was necessary to
develop a specification for the sacks which was done with the assistance of the Paper Shipping Sack Manufacturers Association; (2) unbleached chemical wood fibers were substituted for bleached fibers to conserve chlorine, and groundwood fibers were substituted for chemical fibers; (3) paper patches with water-resistant adhesive were substituted for metal eyelets of shipping tags, and paper tags treated for high wet-strength were used instead of cloth tags; (4) fiber from tow and waste rope was substituted for new cordage-length manila hemp fibers in stencil papers; (5) lens-wiping tissue of high wet-strength made from wood fiber was substituted for Japanese tissue.

Some of the substitute products have proved so satisfactory and have effected such economy that their use will be continued. This is notably true of paper shipping sacks, wet-strength paper shipping tags, and wet-strength wood-fiber lens tissue. The last is definitely superior to the Japanese tissue for cleansing purposes in general and its cost is only 18 percent that of the Japanese product.

The enormous supplies of paper required for warfare, particularly for packaging and communication, necessitated frequent issue of conservation orders and assistance in tapping new sources of supplies on the part of the War Production Board and careful control of ceiling prices by the Office of Price Administration. The latter were important because a balance between costs of labor and the price of the finished product had to be maintained.

The NBS assisted in these problems both in an advisory capacity and by extensive testing. Some of the more interesting developments in this connection follow.

To conserve either the water-proofed cellophane or the metal foil used to wrap cigarettes, it was believed that one of these wrappers might be dispensed with. Tests of packages wrapped in various ways were tested for loss of moisture after exposure to a dry atmosphere with the following results: Packages with cellophane omitted but with the foil intact lost 36 percent of original moisture content after exposure for 120 hours; foil omitted but with cellophane intact, 9 percent; standard packages with both foil and cellophane intact, 8 percent. Therefore the metal foil was omitted. It should be mentioned that the foil in the packages, as is customary, was not sealed—it is an excellent moisture barrier when sealed. A question was raised as to how well the cellophane would retain its initial quality, and therefore newly-made cellophane was aged for six months under ordinary atmospheric conditions and no appreciable change in water resistance, water vapor permeability, tensile strength or stretch was found. Tests were also made to find whether cellophane wrapping was necessary for packaging razor blades. On exposure of packages of blades over a long period to a moist atmosphere, it was found that if waxed paper was used as a wrapper, without cellophane, no rusting of the blades occurred. Accordingly the use of the latter as a wrapper for the blades was banned.

In view of the necessity for the conservation of chlorine, the War Production Board issued an order limiting severely its use for bleaching wood pulp. At WPB request, a study was made to find to what extent unbleached fibers might affect the aging quality of bond papers with respect to the preservation of records. Samples from various manufacturers were subjected to accelerated aging consisting of exposure to dry air at 100°C for 72 hours, and irradiation by carbon-arc light for 40 hours, 20 hours on each side. Under the heat test, papers containing unbleached fibers compared favorably in stability with those containing bleached fibers, but the opposite was true under the light test. When irradiated, the folding endurance and the alpha cellulose of the papers containing unbleached fibers decreased much more than those composed entirely of bleached fibers and also became much more discolored. On subjecting the irradiated papers to the heat test, most of them lost practically all of their folding endurance.
As most record papers are not exposed much to light, it was concluded that for the general run of office records, the papers containing unbleached fibers would serve satisfactorily and the limitation order was kept in effect until chlorine was removed from the list of critical chemicals.

Considerable assistance by testing was given in the development of specifications for special papers and other fibrous products required by the war agencies. This included in many instances, development of testing methods. Some of the products of this kind dealt with, in addition to those mentioned elsewhere, are: waterproofed envelopes for shipping lists which were fastened on the exterior of shipping cases and had to withstand immersion in water; pressure tape for resealing the envelopes of censored mail; safety papers to prevent illegal communications and falsification of records; papers for records and discharge certificates of service men; papers and other sheet materials used for packaging which had to possess a high degree of resistance to permeation of moisture or grease, or both; camouflage paper; paper for parachute flares; sheeting to protect against mustard gas; indicator paper for control of treatment of drinking water with chlorine by combat troops; paper tags to replace metal tags used for marking shipments of steel articles.

Paper Mill Projects

As in World War I, the equipment of the Bureau's semi-commercial paper mill was used continuously in work related to problems brought about by warfare.

In cooperation with the Treasury Department, a further study was made of substitutes for linen fiber used in part in currency paper because the supply of such fiber was at one time threatened by the war. Experimental papers were made of linen, cotton, carna, sisal, and various types of wood fibers and various combinations of these fibers. Some of the papers were surface-sized with glue which was tanned or hardened with alum or formaldehyde. Study was also made of the effect of melamine resin on the properties of the papers. In addition to the usual chemical and physical tests used to evaluate papers of this kind, they were subjected to a crumpling test which simulates service wear of paper currency. The strength, toughness and wearing quality of the papers indicated that the most promising substitutions or addition, yielding paper comparable to that now used for paper currency, would be the use of more cotton fiber, the use of some carna fiber and the addition of melamine resin.

Dyed indicator paper used for testing the condition of explosives was developed and supplied to the U. S. Naval Powder Factory for its own use and also for distribution to the commercial manufacturers and Government plants manufacturing explosives. The base paper formerly used at the Naval Powder Factory for making the indicator paper was of foreign origin and the supply was cut off by the war. As no suitable domestic paper could be found, it was necessary to develop the paper and this was done through experimental paper-making tests. The dyeing was also done at the NBS by a continuous process which gave a uniform product and greatly reduced waste.

Several other types of paper, not available commercially, were developed and manufactured at the request of war agencies for experimental purposes.

Leather

Vegetable-Tanned Sole Leather

Toward the end of 1940, the NBS Leather Section under E. L. Wallace was asked to supply data to set up inspection standards and specifications suitable for procuring large lots of sole leather. Chemical analyses and physical tests were made on samples of sole leather representing the commercial production of a majority of tanners. Studies of the effect of surface defects on wearing quality were made with the leather abrasion machine developed by the Bureau, which indicated that many defects previously considered causes for rejection, would have little influence on the serviceability of the leather, particularly when the soles were used on shoes, such as the Army combat boot, with an
outer tap of another material. The information obtained was used in preparing a revised specification for sole leather (KK-I-261) which served as a basis for procurement by the Army and other agencies.

The problem of tanning leather so as to get the greatest possible length of wear was of interest also to the War Production Board, which asked the NBS to undertake service tests of sole leather. With the cooperation of the Quartermaster Board, wear tests were conducted with troops at Camp Lee, Virginia. The results showed that the differences between commercial tannages were much less than had been generally anticipated, but that there was a definite correlation of wearing quality with such characteristics as firmness, degree of tannage and water-soluble content.

Chrome-Retan Leather

Beginning early in 1942, samples of chrom-retan leather for shoe uppers were obtained from manufacturers experienced in producing this material and subjected to complete chemical analysis and to such physical tests as were then available. With this information, the Bureau recommended certain requirements which served as a basis for the preparation of a specification by the Quartermaster Corps which has been used since 1943.

It was realized that the available tests were unsatisfactory for proper evaluation of the water-resisting characteristics of these leathers, and work has been continued on the development of suitable physical testing methods. Apparatus has been designed for measuring the rate of penetration of water through upper leather during continual flexing, and the amount of absorption and quantity of water transmitted by upper leather while flexing under continuous water pressure.

Shoe Dubbing

Using a formula developed by the National Bureau of Standards to preserve shoe leather, over 20 million 4-ounce cans and 40 million 1-1/2 ounce cans of shoe dubbing were purchased by the Army during the war. The total amount used by all the Armed Services is estimated at over 5,000 tons.

In the Spring of 1941, the Leather section was asked by the Quartermaster Corps to conduct laboratory tests on a large number of commercial materials intended to preserve shoe upper-leathers, in order to find a much better product than the mixture used as a dubbing during World War I. When it was reported to the War Department that none of the materials was regarded as thoroughly satisfactory for field use by soldiers, the Bureau was requested to develop a suitable dubbing.

The research job was completed by the Leather section in 40 days and within a few weeks the Army had started the production of millions of cans of the mixture. The Navy and Marine Corps also used this dubbing.

In 1944, the Chemical Warfare Service and the Quartermaster Corps asked the Bureau to develop a new material that would perform the functions both of the shoe dubbing and of the *Impregmite* used to treat shoes for protection against vesicant gases, and that would also be acceptable as a cold-climate dubbing. The new protective dubbing resulting from this work was adopted as standard by the Army in the summer of 1946.

Leather for Mukluks

The leather used for the uppers of mukluks (high-topped footwear for use in cold, dry, snowy climates) requires an unusual combination of physical properties. The kind of skin that had been most generally used for this purpose was the South American jack buck or deerskin. It appeared in 1942 that the supply of these skins would be inadequate for military purposes. Accordingly, the Quartermaster Corps asked the NBS to make physical and chemical measurements on several kinds of skins from other sources, tanned by different methods. These included goat, pig, deer, steer, calf, kip and seal skins. The tannages tested were chrome, vegetable, synthetic tanins, zirconium, alum and formaldehyde. Some special treatments involving the waterproofing of cowhide leathers and perforation of the leathers with small holes were also investigated.

Kip skins (half-way in maturity between a calf and a cow) were found to give leathers
most nearly resembling that from the jack buck. When tanned with formaldehyde, they were perhaps even superior in some respects.

As white mukluks are used for protective colorations in snow, they tended to become soiled rather quickly. A method for cleaning and reconditioning mukluks was devised for the field use of the Army.

Iron Tannage

An NBS investigation of ferric sulphate as a tanning agent resulted in the first iron-tanned leather that is satisfactory with regard to flexibility, appearance and aging qualities. The work was undertaken in February 1942, because of the danger that the war might cut off this country’s principal foreign sources of chromium ores, from which come most of our materials for tanning leathers for shoe uppers, garments and gloves. Previous work elsewhere had shown considerable promise for iron as a tanning agent, but the resultant leathers were too stiff, lost strength on aging, or had an unstable tannage.

It was found possible to stabilize solutions of ferric sulfate at pH values up to 6.0 with acetic, lactic, citric, hydroxyacetic and gluconic acids. Maximum fixation of iron by hide was found at pH 3 to 4.

Practical tanning experiments were made with goat skins and calfskins. A combination of oils was developed which would give the leather the desired flexibility. Accelerated aging tests showed that citric acid as a stabilizer gave iron-tanned leather with the best aging qualities. Such leather kept in storage three years has shown no appreciable loss in its original strength and flexibility.

Compounds for Treating Soles

Work on sole-treating oil compound was started in September, 1941, as a result of a letter from the War Department reading:

"In view of the recent successful development of the new shoe dubbing formula and specifications by the Bureau, it is requested that the Bureau of Standards develop a waterproof sole-dipping compound."

Laboratory examinations were made on representative samples of about 30 available commercial materials intended for the purpose from which two oily mixtures were selected for actual service tests at Camp Lee, Virginia. The treatments were found to improve the wear of sole leather of military quality only about 7 percent, and consequently were not regarded as economically justifiable for Army shoes.

However, service tests showed an improvement of 14 percent in the wear of sole leather of grades available for civilian use at that time, when treated with either of the two selected mixtures. The shoes in these tests were worn by students at the Woodrow Wilson High School in Washington, D.C.

Later, the University of Cincinnati found that the addition to the mixtures used of 25 percent or more of heavy fatty oils, not available in large quantities at the time of the NBS work, would improve the wear about 25 percent.

On the basis of those experiments, the NBS assisted the Army in preparing specifications which were used for the oil treatment of shoes for the Women’s Army Corps, for Army nurses, and for Russian War aid.

Service tests were also made on four wax compositions for treating soles all of which showed an improvement of about 40 percent in wear. Service tests of a commercial treatment containing a plastic showed an improvement of about 16 percent in wear.

Insoles

Examination of worn-out shoes returned to factories for rebuilding showed that one of the chief causes of failure was deterioration of the insoles. The Quartermaster Corps therefore requested that the NBS, in cooperation with the Tanners’ Council Laboratory and the U.S. Department of Agriculture, undertake studies leading to the development of improved insoles.

Chemical analysis of damaged insoles showed that the deterioration was apparently caused by perspiration, which is alkaline with respect to insole leather. A test to simulate the effect of perspiration, using synthetic perspiration solution for treating
the leather and a flexing action such as that found in service, was developed in the laboratory. A convenient apparatus for conducting such a test was constructed at the Tanners' Council Laboratory.

Insoles were given various treatments designed to lengthen their useful life and then exposed to the perspiration tests and to physical tests. Based on this information, treatments including mineral oil, special solubilized oil, buffer salts and an aluminum retannage developed by the Eastern Regional Research Laboratory were recommended to the Office of the Quartermaster General for service tests. The service tests made in Army shoes confirmed the predictions based on the laboratory tests.

Outsoles

Several promising new materials for shoe soles were developed by industry during the war in the search for substances to take the place of leather. The Bureau assisted in this work by devising testing methods, developing performance standards and testing new materials and making suggestions for their improvement.

Minimum performance requirements for substitute sole materials were set up for the War Production Board in July, 1943. These were adopted by the Board for use in allocating raw materials, and by the Office of Price Administration as an assistance in pricing new sole materials. The use of these specifications had the effect of keeping off the market a number of materials of poor quality, and as a result the volume of complaints from consumers about poor sole materials began a marked decline. One of the types of materials that appeared particularly promising for shoe soles was vinyl resin.

Rebuilding of Shoes

The rebuilding and sterilization of worn shoes was one of the methods employed by the Army to reduce its consumption of leather as much as possible. When soldiers' shoes became so badly worn that ordinary repairs were no longer practicable, they were not thrown away, but sent to a rebuilding factory. The shoes were washed and sterilized, worn-out parts were replaced by new parts, and the shoes were re-lasted and refinished. The product was equivalent to a new shoe, with an estimated saving of $1.60 per pair on some two million pairs per year.

The NBS assisted in setting up the cleaning and sterilization processes. Tests of the physical and chemical properties of the leathers before and after rebuilding were made. These showed that the leathers were not adversely affected, and that the rebuilt shoes could be expected to give service equivalent to new ones.

Mildew and Fungicides

Prolific growth of mildew on leather is a common occurrence in the tropics. Little was known about the effect of mildew on leather, other than its appearance. To study this problem, vegetable-tanned strap leather was exposed to various conditions favoring the growth of mildew. It was found that the fungi used the oils in leather as a nutrient. The loss of oil, particularly in the surface layers, resulted in a decrease in the tensile strength, elongation and flexibility of the leather. To counteract this effect, an oily compound containing a fungicide was developed, which was put up in small cans and supplied by the armed services to troops in the tropics.

Mildewing of Military Equipment

During the Fall of 1940, the Corps of Engineers of the United States Army, mindful of the fact that the rotting of military fabrics and other material was inevitable, called upon the NBS to assist them in controlling this costly waste of equipment. The project was undertaken by R. F. Tener. Up to that time little work had been done on the mildewproofing of fabrics and other materials. Mildew had been accepted for axes as a necessary evil. The first job given to the Bureau by the Engineers was the testing of mildew-resistant sandbag fabrics. A tentative specification was submitted by the corps of Engineers, which involved the use of a pure-culture of the mildew organism Chaetomium globosum. The test method was
based on a procedure developed by Thom and Humfeld of the U. S. Department of Agriculture. Under sterile conditions samples of fungicide-treated jute and cotton osnaburg are inoculated with pure cultures of Chaetomium globosum and are incubated for 14 days at 26°-30°C, after which the breaking strength is determined and compared with the original breaking strengths. Any loss of strength greater than 10% is considered significant. Untreated fabric of the same type is completely degraded when tested in this manner.

This test method was the only one available and had to be used in spite of its unsuitability. This meant that in addition to testing, new test methods had to be developed. The first change in the test method was necessitated by its inordinately long incubation period which was followed by tedious breaking-strength determinations. Inasmuch as the test, as originally set up, required a minimum of 21 days from the receipt of the fabric until the final results were obtained, samples were accumulating faster than they could be tested. Furthermore, the Corps of Engineers, much concerned with the possibility of war, were eager to get the program well under way without delay. Thereupon, an intensive study was made of the growth characteristics of Chaetomium globosum in the presence of the materials to be tested. The study quickly brought forth the fact that there was a definite correlation between the breaking strength of mildewed fabric and the degree of growth of Chaetomium globosum as seen with the unaided eye. Furthermore, it was not necessary to wait 14 days for results. The degree of growth at the end of 7 days was always an indication of the degree of physical breakdown at the end of 14 days. When there was no growth in 7 days there was none in 14 days, and also no loss in strength. Therefore, it was decided that if a specimen showed any growth to the unaided eye in 7 days it was to be rejected. With this new method pioneered by the Bureau of Standards, the procuring of mildew-resistant sandbag fabrics was greatly speeded-up, fabric for approximately 5 million sandbags were procured and reports from overseas indicated that the cost of this program was eminently justified.

From the start the Engineers had suggested the use of three copper compounds: copper napthenate, cuprammonium and copper ammonium fluoride. These compounds were effective if used in the proper concentration. However, due to the peculiarities of the fabric it was not always sufficient to determine chemically whether the correct concentration was present on the fabric. A fabric might assay the correct concentration of fungicide and yet give a spotty growth of mildew in the Chaetomium test. A study of this problem showed that the structure of the fabric, especially of the burlap, was responsible for this condition. The fabrics are fairly uneven, having occasional woody portions or seed hulls which are thicker than the surrounding fibers. Consequently, they take up fungicide to a different degree than the fiber itself. Furthermore, when the fabrics are passed through wringer rolls to remove excess fungicide, these high places are squeezed excessively and retain correspondingly less fungicide than the surrounding areas. These are focal points of mildew attack. Many thousands of yards of treated fabrics which contained the required amount of fungicide were rejected for this reason. After an initial adjustment period of about two months, during which processors were learning how to apply these new materials, surprisingly few samples were rejected. Manufacturers were assisted in setting up their own mildew-testing laboratories and were supplied with pure cultures of Chaetomium globosum and other organisms from our bank of pure cultures.

In addition to testing materials for procurement, it became necessary to evaluate new fungicidal treatments as they were submitted by manufacturers. It had been intended to use the Chaetomium test for this work, but Chaetomium globosum is inhibited by relatively low concentrations of fungicide. One of the best fungicides is copper napthenate and the specification requires 0.8% copper based on the finished weight of the fabric. However, as little as 0.3% copper as copper napthenate will completely inhibit the
growth of Chaetomium globosum in the laboratory, but this is not true when the material is used in the field. Low concentrations of copper naphthenate—as well as of other fungicides—soon became ineffective. In order to have a degree of permanency in an effective fungicide, a safety factor is required. A fungicide must be relatively insoluble in water although a slight degree of solubility is necessary to make it act. If a fungicide is slightly soluble, how long will it take before it is completely removed from the fabric by the action of the elements? The investigation was not concerned with water alone for, as was soon learned, some fungicides are broken down by the action of light and liberate end-products such as hydrochloric acid which have a deteriorating effect on cellulose fabrics.

To test these factors, use was made of a carbon-arc weathering device in which specimens were exposed to alternate periods of wetting and drying and to the rays of a carbon-arc lamp. After 360 hours of accelerated weathering the specimens were given a Chaetomium test. Now it could be seen that 0.3 percent copper as copper naphthenate was not sufficient to pass the Chaetomium test after accelerated weathering. This gave a method for comparing fungicides with regard to their permanence and for determining adequate concentrations for field use. With this method it was possible to evaluate a large group of fungicides. Those which failed to pass the Chaetomium test were rejected at once. Those which passed the accelerated weathering test and a subsequent Chaetomium test were considered as acceptable fungicides with no method for differentiating their relative effectiveness. Therefore, the soil burial test was employed which is the most severe microbiological test method known today. The specimens were buried in moist soil, maintained at 85° - 90°F in tight cabinets, with the air at a relative humidity of 95 percent. If a material survives 9 weeks of burial with insignificant strength loss, it is considered to be good. Anything which lasts 12 weeks is outstanding.

In developing mildew-resistant camouflage materials, the primary problem was not loss of tensile strength but one of maintaining a specific color. If the camouflage surface became mildewed, its color was altered with disastrous results. The organisms involved are the prolific surface growers, of which the genera Aspergillus and Penicillium are the most common members. An accelerated test was developed using Aspergillus niger as the test organism, which has been adopted by all workers in the field as the standard tests where the effect of surface-growing organisms is important. Mildew-resistant camouflage materials are discussed more fully elsewhere.

Shortly after the outbreak of the war it was found that practically all materials were subject to mildew in the South Pacific area. The Bureau was called upon to assist other agencies of the Government in solving mildew problems. It was found by coordinating the Chaetomium test and the Aspergillus test, practically any material could be tested to determine its fungicidal potency. Although Chaetomium globosum is specifically a cellulose destroyer, it was found that it could derive its carbon from other sources—especially fatty acids, which made it particularly useful in testing the plasticizers used in compounding plastics. Aspergillus niger was found to be especially partial to materials containing protein so that it was effectively used in testing mildew-resistant wool.

The Maritime Commission developed a life-raft blanket for shipwrecked sailors which had to be made mildew-proof. By making use of both the Chaetomium and Aspergillus tests effective fungicides for wool were soon found. These blankets were made water-resistant by the use of a vinylite-coated cotton cover. It was found that the vinylite could support a copious growth of mildew, especially Chaetomium globosum. A study of the components of vinylite showed that the only constituent which supported a growth of mildew was a ricinoleic acid derivative which had been used as a plasticizer. It was found that if tricresyl phosphate was substituted for the ricinoleic plasticizer the finished product would not support a growth of mildew. This discovery led to an extended study of the
growth of mildew on plastics, which showed that mildew-resistant plastics could be compounded from properly selected components. The work was sponsored both by the Bureau and NDRC, and involved the study of 20 plastics and 118 plasticizers. The results have been of great value to manufacturers and procurement agencies and have been published by the National Defense Research Committee as a restricted paper.

Assistance was given the Bureau of Aeronautics of the Navy in obtaining mildew-resistant airplane fabrics and dopes. This work was carried on in cooperation with the Plastics section of the Bureau.

In cooperation with the Leather section of the Bureau, a study of the mildewing characteristics of shoe leathers was carried on for the Office of the Quartermaster General. The Aspergillus niger test was particularly well suited for this material. It was found that although the leather substance itself was not damaged by the mildew which grew upon it in abundance, the important oils in the leather were removed. This led to the cracking of the leather. To control the growth of mildew on leather, an oil treatment containing a fungicide was developed by J. R. Kanagy of the Leather section. This compound was put up in small cans with a self-contained brush and supplied to all troops in the South Pacific area. Applications to shoes and other leather articles could be made as needed.

Owing to the shortage of high-grade leather, the War Production Board found it necessary to specify cotton webbing as a substitute in the manufacture of harnesses for horses. The NBS aided by manufacturers, was instrumental in developing a satisfactory mildew-resistant harness webbing.

Other mildew-resistant materials which the Bureau has either developed or assisted in developing include: pneumatic floats, laminated glass fabric armor plate, ropes, tent duck, packaging paper, lacquers, map paper and map cloth, cloth measuring tapes, water tanks, netting, fire hose, insect screening and cable coverings.

Mass Spectrometer Analyses

During February 1944, the National Bureau of Standards installed a Consolidated mass spectrometer in its Mass Spectrometer laboratory under A. K. Brewer. This instrument was acquired primarily for the analyses of materials used in the manufacture of synthetic rubber. Its usefulness, however, was soon extended to the analyses of a large variety of gases and hydrocarbons for the War and Navy Departments, including a number of captured German rubbers and plastics.

Since its installation, some 3,000 samples have been analyzed. Approximately 500 of these have been reported to outside agencies, while the remainder have been for the Bureau.

The advantages to be gained by the use of the mass spectrometer are many. Only 0.1 cc of gas is necessary for an analysis. Owing to the smallness of the sample required it was possible, for example, to determine the gas composition in blisters forming under the insulation in airplane ignition cables. Hydrocarbon mixtures can be analyzed which cannot be readily separated by any other method. As many as 30 hydrocarbons in a mixture have been identified and the concentration measured. The minimum quantity of material that can be detected is of the order of 10 parts per million, but may be appreciably less than this in the presence of closely related compounds. This relatively high sensitivity has been extremely useful in the detection of traces of impurities in the monomers used in synthetic rubber. A millionth of a gram of material can be detected. The mass spectrometer laboratory is now working on techniques to make possible the application of this new method of micro-analysis.

The rubber analyses made on the mass spectrometer have been largely for the different rubber companies, for research authorized by the Office of the Rubber Director and for the Government Evaluation plant in Akron, Ohio. The materials analyzed have been primarily butadiene, styrene, vent gases and recycle from the copolymer plants. The
monomers entering into the manufacture of all varieties of synthetic rubber have been analysed.

Regular cross-check analyses have been made on butadiene samples submitted monthly to various companies and agencies for test. These analyses have checked consistently with freezing-point measurements made by F. D. Rossini and his co-workers within the limits of error prescribed. A special molecular pyrolysis technique has been developed for the analyses of high polymers, such as rubbers and plastics, which have too low a vapor pressure for direct analyses in the mass spectrometer. The procedure consists of subjecting a sample of material to thermal decomposition at 400°C in small highly evacuated molecular stills so designed that the initial breakdown products of the polymer are frozen out at liquid air temperatures without themselves undergoing decomposition. This technique is of special interest in that it opens up an entirely new field to mass spectrometric analysis, i.e., the heavy molecule field.

Results obtained on the analyses of plastics and rubbers have been very gratifying, since the various polymers break down into the original monomers or into characteristic fragments. To illustrate, from polyisoprene or smoked crepe better than 90 percent yields of isoprene have been obtained. Polybutadiene, in contrast yields only a moderate amount of butadiene, the major portion breaking up into a large number of disintegration products. The pyrolysis technique has been applied successfully to the analyses of captured German rubbers and plastics. It was even found possible to analyze the plastics used to impregnate articles of clothing.
13. Ceramics, Metals, Alloys

Ceramics

The trend toward higher temperatures in such applications as jet propelled airplanes and gas turbines has resulted in the need for materials capable of withstanding the high temperatures inevitable in this equipment if adequate efficiencies are to be attained. Coincidentally, such a material must have a high resistance to corrosion and oxidation. In general, metals decrease in strength with increasing temperature and are susceptible to corrosion and oxidation. Ceramics, however, represent a class of material which meet the above demands, and considerable research has been undertaken in recent years directed toward the development of the best ceramics for such critical purposes as jet engines.

In addition, ceramics afford a material with highly desirable electrical characteristics for high frequency fields. The urgent need during the war for special dielectric materials in connection with such projects as radar and the proximity fuze as well as the requirements of jet engines accelerated research in ceramics.

Special Porcelains

A conventional pottery body is a very complex structure of crystalline silicates in a matrix of glass. This glass, in common with all glasses, does not have a sharply defined fusion point and will deform under stress at temperatures much lower than the temperatures at which the crystalline phases liquify. For high strength, particularly at elevated temperatures, the desideratum is a crystalline body of simple composition and preferably of fine structure.

In anticipation of industrial and military needs for such porcelains, an NBS investigation under R. F. Geller was started in 1940. The first development was a furnace in which preformed ceramic shapes could be fired under oxidizing temperatures in excess of 1800°C with closely controlled rates of heating and cooling.

The second phase of the investigation was undertaken to obtain the fundamental information upon which the practical work of producing ceramics to meet future demands could be based. This involved the study of variously heated binary and ternary combinations of CaO, BeO, BeO, MgO, Al₂O₃, ThO₂, and ZrO₂ both as practically pure oxides and with minor additions of other oxides. The program included a limited survey of phase relations as well as the preparation and testing of vitreous or porcelain-like specimens. The tests covered the determination of the so-called vitrification range, mechanical strength, electrical characteristics and other properties having a bearing on the usefulness of the compositions.

In the system BeO-Al₂O₃, large crystals and also vitrified specimens of chrysoberyl (BeO-Al₂O₃) were obtained readily at 1840° to 1865°C. The electrical resistance of chrysoberyl was very good (Tₑ = 1285°C), where Tₑ is the temperature at which a centimeter cube of the material has a resistance of one megohm. The compressive strength and thermal conductivity of chrysoberyl were only fair. The dielectric constant was 7.7, and the dielectric loss angle was 0.01 percent.

In the system MgO-BeO, a simple eutectic was located at 1865°C and 46.2 weight percent of BeO. Compositions containing not less than about 80 weight percent of BeO could be vitrified at 1600° to 1830°C. Strength in compression was fairly high (84,000 to 167,000 psi), electrical resistivity was good (Tₑ 1150° to 1200°C), and the thermal conductivity of specimens containing about 70 or more weight percent of BeO was practically equal to that of pure BeO.

The system MgO-BeO-Al₂O₃ was thoroughly investigated in the NBS Ceramics laboratory under R. F. Geller. A considerable number of compositions containing less than 30 weight percent of MgO could be vitrified at from 1500° to 1725°C. Those high in BeO content were the most promising. Compressive
strength of over 250,000 psi was developed, the $T_p$ value ranged from 1140 to 1210°C, the dielectric constant ranged from 6.5 to 7.7, and the dielectric loss angle from 0.21 to 0.06 percent.

The system BeO-Al₂O₃-ThO₂ is distinctly one of high temperatures. The optimum temperature interval for producing vitreous specimens of certain compositions was 1600° to 1750°C. Compressive strengths in excess of 250,000 psi were found. Two compositions showed an electrical power loss of less than 0.01 percent, and the dielectric constant averaged about 7.5. As in all of the systems investigated, the thermal conductivity was directly proportional to the BeO content.

Tests for determining relative resistance to attack by PbO vapor, such as encountered by spark plug insulators in the cylinders of engines using fuel with an admixture of tetraethyllead, indicate that siliceous bodies were the least, and "high BeO" bodies were the most, resistant to attack. Preliminary tests show also that many of the vitrified compositions have excellent strength at elevated temperatures, moduli of rupture in bending of over 12,000 psi at 980°C having been determined, and specimens high in BeO content combine this high strength with high resistance to thermal shock.

**Mechanical Strength of Ceramics**

The purpose of this project was to establish the possibilities of ceramics as replacements for high-temperature metallic alloys in such applications as jet propulsion and gas turbine engines. The scope of the work as outlined does not include the development of special ceramic compositions, but rather the utilization of special porcelains available from the industry or from laboratory research. Two producers of porcelains cooperated by supplying appropriate preliminary specimens of several of their compositions. None of the commercial materials appeared as promising as the compositions developed at the Bureau during the investigation of special porcelains. As a consequence, the study of strength in pure tension at elevated temperatures, sponsored by the NACA, was confined to specimens of our own compositions and to the one most promising commercial composition.

Seven compositions were selected after extensive testing for the high-temperature creep-tests in tension, and elaborate equipment was installed to insure satisfactory temperature control, specimen alignment and load application. The test procedure, in general, consisted either in raising the temperature in steps using a constant load, or in raising the load in steps with the temperature constant. So far, stress at failure has ranged from 7,000 to 15,000 lb per sq. in. for test temperatures ranging from 1,500° to 1,800°F.

As a result of this work, which is still far from completion, it may be said that ceramic materials for turbine blades and other parts exposed to corrosive gases at higher temperatures show decided possibilities, and that certain compositions are promising enough to warrant simulated and actual service tests in the laboratory and in operating installations.

**High Frequency Dielectrics**

Modern ordnance equipment, such as the proximity fuse and the new pocket-size radio receiving sets, require high-capacity condensers of very small volume. Common types of dielectrics for condensers, such as paper and mica with dielectric constants less than 10, require too great a volume for a tiny installation such as a proximity fuse. Therefore, at the request of the Signal Corps, an NBS investigation directed by E. N. Bunting was begun to discover materials with high dielectric constants and other requisite physical properties to replace these materials. Although it was known that some recently developed condensers have dielectrics made from titanates and various titanates, showing generally favorable properties, there was little published information concerning the effects produced by small variations in composition on the properties of such materials.

Systematic investigations as a part of this work thus far have included titanate bodies containing the oxides of barium, strontium, calcium, and magnesium. The
bodies were dry-pressed (20,000 psi) in the form of discs (0.1 in. thick by 0.375 to 1.0 in. in diameter) and heated (1285° to 1450°C) to maturity, as indicated by low values of porosity (0.1 to 0 percent). After coating both faces of the discs with silver, measurements were made of the dielectric constant and power factor at frequencies of 50 to 20,000 kilocycles per second. The effect of the temperature of the discs upon the dielectric constant was also observed.

Discs with compositions in the system BaO-SrO-TiO₂ exhibited at room temperature dielectric constants varying from 35 to 18,000 and power factors from 0.01 to 0.0001. The highest dielectric constants (10,000 or more) were observed on a series of discs with varying content of barium and strontium titanates as the end members of the series. The pronounced effect of temperature upon the dielectric constant of these discs is illustrated by the following tabulation of data obtained on the barium titanate disc.

<table>
<thead>
<tr>
<th>Temperature °C</th>
<th>Dielectric Constant K (1,000 kc/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>1370</td>
</tr>
<tr>
<td>60</td>
<td>1300</td>
</tr>
<tr>
<td>80</td>
<td>1400</td>
</tr>
<tr>
<td>100</td>
<td>1180</td>
</tr>
<tr>
<td>105</td>
<td>1180</td>
</tr>
<tr>
<td>115</td>
<td>2800</td>
</tr>
<tr>
<td>117</td>
<td>3650</td>
</tr>
<tr>
<td>118</td>
<td>1500</td>
</tr>
<tr>
<td>119</td>
<td>1200</td>
</tr>
<tr>
<td>122</td>
<td>8400</td>
</tr>
<tr>
<td>125</td>
<td>7400</td>
</tr>
<tr>
<td>130</td>
<td>6200</td>
</tr>
</tbody>
</table>

Thus the highest values of the dielectric constant are limited to a very narrow range in temperature for a given disc. Beginning with the barium titanate disc, with a peak in dielectric constant at 118°C, the peaks occurred at decreased temperatures as the content of strontium titanate increased in the remaining discs of this series. A number of these discs of properly selected compositions would be required for a condenser with a high average capacity over a given range of temperature.

In contrast to the above series, discs having a higher content of titania exhibited lower values of the dielectric constant which were altered to a less extent by changes in temperature. Tabulated below are data showing the effects of composition and temperature on discs representing a series with barium trititanate (Ba0:3T10₂) and strontium dititanate (Sr0:2T10₂) preparations as the end members.

<table>
<thead>
<tr>
<th>Amount of Ba0:3T10₂ in disc</th>
<th>Dielectric constant K, (1,000 kc/sec), at temperatures of—</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent</td>
<td>-60°C</td>
</tr>
<tr>
<td>100.0</td>
<td>44.6</td>
</tr>
<tr>
<td>92.0</td>
<td>52.4</td>
</tr>
<tr>
<td>84.1</td>
<td>55.0</td>
</tr>
<tr>
<td>71.8</td>
<td>78.9</td>
</tr>
<tr>
<td>60.8</td>
<td>92.6</td>
</tr>
<tr>
<td>48.8</td>
<td>112.0</td>
</tr>
<tr>
<td>34.0</td>
<td>160.0</td>
</tr>
<tr>
<td>16.0</td>
<td>220.0</td>
</tr>
<tr>
<td>.0</td>
<td>....</td>
</tr>
</tbody>
</table>

Further increase in the content of titania resulted in decreasing values of dielectric constant until a minimum of about 35 was reached at a molecular ratio of approximately Ba0/4T10₂, beyond which the values increased to about 100 for pure titanium oxide.

Although variation of the frequency (50 to 20,000 kc/sec) resulted in relatively small changes in the values of the dielectric constant of all of the discs, considerable changes were found in the values for Q, the reciprocal of the power factor. In general, discs with a high content of SrO and TiO₂ have low dielectric losses, as indicated by high values of Q, whereas discs with a high content of BaO have higher losses.

**Ceramic Coatings**

At the time of our entry into the war, stainless steel was the accepted material for fabrication of aircraft engine exhaust stacks, which encounter severe conditions of oxidation, thermal strains and high temperatures. Stainless steel, however, requires
alloying metals, such as chromium and nickel, which were expected to become critically scarce. A study was therefore undertaken by the NBS Enameded Metals section under W. N. Harrison to develop a ceramic coating which could be applied to ordinary steel and would protect it against corrosion under the severe conditions of service. This work was begun in 1942 and proceeded in active cooperation with the armed services. Members of the porcelain enamel industry contributed by submitting samples of their most promising coatings for comparative tests.

After some experimentation a coating was developed having properties markedly superior, for the intended purpose, to any others heretofore available. The outstanding features of the NBS high-temperature ceramic coatings are (1) extremely high resistance to chipping under repeated thermal shock, (2) prolonged protection of the metal against oxidation at temperatures up to 1250°F, (3) resistance to the cracking and blistering which is produced in conventional porcelain enamels under comparably severe conditions of high temperature and thermal gradients, and (4) a surface which does not give glare by producing highlights and therefore maintains low visibility.

Following extensive laboratory tests in the initial development work, a variety of service tests were made on the coatings under the auspices of the Army Air Forces, the Navy Bureau of Aeronautics, and the Tank Automotive Center of the Army Ordnance Department; similar tests were made by a number of the large aircraft manufacturers. These experiments showed, without exception, the superiority of the NBS ceramic coatings over the conventional type of porcelain enamel coatings on which parallel tests were conducted, and also over non-ceramic coatings when these were included in the comparisons. At the request of the Armed Services, specifications covering the new type of ceramic coatings were prepared. They were issued as Army-Navy Aeronautical Specification AN-C-183, and as tentative specification AXS1449 of the Army Ordnance Department.

Commercial production of low-carbon steel exhaust stacks with the NBS ceramic coating was started in 1944. By the end of the war three enameling companies had applied the coating to stacks in substantial quantities for use on a number of models of aircraft. The coating thoroughly proved itself in all tests on short stacks for aircraft, and could have been adopted for this purpose throughout the industry had the shortage of nickel and chromium for alloy steels become sufficiently acute to limit their use for aircraft production. Since the shortage of stainless steel never developed to that extent, the selection of the NBS ceramic coating for this purpose was through preference of the manufacturers and based upon test results rather than upon enforced substitution.

Coatings for Alloys

The work done by the Bureau in developing high-temperature ceramic coatings for low-carbon steel led indirectly into a field involving the development of protective coatings for high-temperature alloys. Since the efficiency of gas turbines increases with operating temperature, a limiting factor in obtaining increased efficiency is the maximum gas temperature that the alloys available for their construction will withstand. Durability of the alloys under the operating conditions is of course important and is especially in need of extension in certain sheet metal parts of the power plants for jet-propelled aircraft. The possibility that ceramic coatings might extend the maximum operating temperature, or the life at current temperatures, of the alloys used for such purposes was considered by the NACA, and in May of 1944 a cooperative project was arranged with the NBS with this object in view.

The Enamel Metals section was enlarged to handle this new assignment, and new equipment was installed for the investigation. A large number of experimental coatings for the special alloys were tested, but by the end of the war the study was still in the laboratory stage.

Another application of the NBS ceramic coating which reached the production stage
before the end of the war was the coating of tail pipes for the amphibious truck or "DUCK". One section of this pipe is 9 feet long, and two others are approximately 3 feet and 2 feet long, respectively. These pipes were originally fabricated of low-carbon steel without coating and were failing rapidly in service, especially in the South Pacific. By the end of the war, they were being produced in a substantial quantity with the NBS A-19 ceramic coating.

When the success of the NBS ceramic coatings for protection of steel at high temperatures became better known in the Armed Services, a number of applications occurred to those responsible for development work, and the Bureau was asked to coat a variety of specimens for test. While most of these applications did not reach the production stage, several of them proved successful. Among the items of which favorable results were obtained might be mentioned gun-blast tubes for machine guns in aircraft and gas-expansion cylinders for the M-1 automatic rifle. For both of these applications the requirements included resistance to high temperatures and to sudden temperature changes, good adherence, and abrasion resistance, and a dark, nonglossy finish, all of which were provided by the NBS ceramic coating. One of the more serious maintenance problems for submarines and landing craft during the war was the mufflers. With both of these types of sea-going vessels the success of many of their missions depends upon silent operation, and this requires an effective muffling of the engine exhausts. At the beginning of the war the mufflers were fabricated of uncoated low-carbon steel, and many corrosion problems developed. In the South Pacific, muffler replacement on submarines was required after each mission. Four mufflers, weighing approximately 3,000 pounds each, are required on each submarine. Therefore, prolonging the muffler life became important in relieving transportation problems as well as in reducing the man-hours involved in maintenance.

By the summer of 1944, the problem had become so acute that the Bureau of Ships enlisted the aid of the NBS in seeking a solution. Galvanizing had been tried and was no better than the uncoated metal. Baked-on organic coatings also failed to give the necessary protection, the best possibility seemed to be the ceramic coating.

Through a cooperative project with the Bureau of Ships, a program of study was carried out in which the facilities of the Naval Engineering Experiment Station at Annapolis provided for the testing work while the coatings were designed and applied at the NBS. Because of the cooling water introduced into the mufflers and the lower exhaust gas temperatures of the Diesel motors as compared to aircraft engines, the service data accumulated on the aircraft exhaust systems were not applicable to this problem. A number of modifications of the high-temperature ceramic coatings developed at the Bureau, and of several commercial-type enamels, were included in the study.

Before the testing program had been completed, however, the need for coatings on the mufflers was so pressing as to make immediate production desirable without waiting for the full results of the testing program. NBS coating A-188 was believed to show the most promise at this stage of the investigation, and in October of 1944 production was started using this composition. As production progressed, modifications of the coating were believed desirable to facilitate application, and these modifications were made by the manufacturer. By the end of the war the mufflers were being coated in a considerable quantity in a plant especially equipped for the purpose by arrangement with the Bureau of Ships.

Porcelain Enamed Products

Early in the war the shortage of aluminum was so severe that it became desirable to find a substitute material for the production of canteens. Porcelain enamel on steel was already being used by the British for this application, and following conferences between members of the Quartermaster Corps of the Army, the Office of Production Management, and NBS, specifications for enameled canteens were prepared and submitted. Later, various samples were submitted to the Bureau for test and a number of suggestions
were made for improvements. A considerable production of the enameled canteens took place during 1942, after which aluminum again became less critical and production of canteens fabricated from this metal was resumed.

At the request of the Quartermaster General, an inspectors' manual for porcelain enamel items was prepared by a member of the NBS staff. This manual was published by the Quartermaster Corps and was distributed to all War Department inspectors of porcelain enamel items.

A testing program on porcelain-enameded mess trays was undertaken at the request of the Maritime Commission. As a result of this work, a specification covering this item, with requirements based on the data obtained, was formulated.

The two most common materials used for hot water storage heater tanks before the war were galvanized steel and monel metal. A few of the so-called "glass-lined" tanks had been produced, but there were not sufficient service data available to determine the durability of various enamel types and to serve as a basis for specifications. The Enamels Metals section, working in cooperation with the Trade Standards division, developed tests whereby the durability of various types of porcelain enamels against attack by hot water could be determined. The loss of gloss of the enamel, under a standard treatment in contact with boiling water, was measured and a limit set upon the permissible loss in a specified accelerated test. This provided a basis for a substantial improvement in the quality of enamel-lined tanks obtained by the government for defense housing.

Aluminum Silicate Coatings

One of the many war-time developments in coatings for metal was the "so-called aluminum-silicate type. These coatings are inorganic in origin and are applied by spraying, after which they are cured at temperatures up to 750°F. The Army Quartermaster Corps became interested in these coatings for special purposes involving temperatures too high for paints and baked-on organic enamels to withstand. Largely on the basis of simulated service tests made at the NBS by request of the Army, these coatings were adopted by the Quartermaster Corps as war-time finishes for such parts as field ranges and spark arresters for sheet-metal stacks.

Steel and Steel Alloys

Effect of Boron

It is now recognized that the hardenability of some types of steel may be materially increased by proper treatment with so-called "intensifiers," "addition agents," or "needling agents" containing boron. The effectiveness of the treatment depends upon the steel making practice and the final boron content of the steel. Available information indicates that optimum hardenability may be obtained in certain grades of steel when either simple or complex ferro-alloy is added to strongly deoxidized heats, so that the "residual" boron is within the range of about 0.001 to 0.005 percent. This effect of boron on hardenability suggests the possibility that boron may be substituted for a part or all of the strategic elements now commonly used as alloying agents in steel for armor plate or for other military applications.

A study therefore was carried out at the NBS under T. G. Digges to determine quantitatively the effects of boron additions on some properties of steel used for armor plate and other military applications. Special attention was directed to the development of chemical and spectrographic methods, suitable for commercial use, for accurately determining small amounts of boron in steel. The investigation was divided into two main parts, namely: (1) a study of the interrelation between boron, carbon and alloying elements on some properties of steels made in the laboratory; and (2) a study of the properties of boron-treated steels made commercially under predetermined deoxidizing practice. The testing program included a study of the cleanliness of the steels and structures as hot-rolled, normalized and heat-treated; determination of the austenite grain size established at temperatures within and above the usual heat treating range
and of the McQuaid-Ehn grain size (carturized at 1700°F for 8 hours); determinations of the hardenability (Jominy), notch toughness (Charpy impact) at room and low temperatures, and tensile properties at room temperature.

The plan for the investigation was prepared jointly with the War Metallurgy Committee, and the project was carried out under the auspices of this committee with funds transferred by the OSFD for a period extending from October 1942 to September 1944. The plans for testing the commercial steel at the NBS were prepared jointly with the War Engineering Board, Iron and Steel Committee, War Metallurgy Committee and Army Ordnance.

The assembly of armor on the equipment used by our armed forces is commonly done by welding. Since steels with carbon in excess of about 0.30 percent do not have the desired weldability, attention was directed to a study of the experimental steels containing 0.30 percent carbon. Some 250 experimental and 20 commercial steels were used. An Ingot without boron was prepared from each heat to use as a basis for determining the effect of boron. This was essential because of the wide variation in hardenability often observed in steels that are nearly alike chemically. The experimental steels were prepared at the Battelle Memorial Institute by induction melting without the use of a slag, whereas the commercial steels were from a basic open-hearth heat prepared by the Carnegie-Illinois Steel Corporation for Army Ordnance.

The results of the tests made on the experimental and commercial steels lead to the following general conclusions:

1. Boron in steel may be determined chemically by a colorimetric method using phosphoric acid and turmeric. An accuracy of ± 0.0002 percent boron may be obtained in the lower part of the range from 0.0005 to 0.006 percent, while an accuracy of ± 0.0005 percent is possible in the upper part of this range. The average difference between determinations by chemical and spectrographic methods was about 0.003 percent.

2. Variations from nil to 0.006 percent boron made with intensifiers, with or without grain refining elements, had no significant influence on the following properties of the steels: (1) cleanliness (non-metallic inclusions); (2) hot working; (3) transformation temperatures; (4) resistance to softening by tempering; (5) tensile strength when fully hardened and tempered, except possibly an improvement in ductility when tempered at low temperatures.

3. Boron lowers the coarsening temperature of austenite. However, steel with relatively high additions of boron can be rendered fine-grained at heat treating temperatures by the judicious use of grain-growth inhibitors, such as aluminium, titanium, zirconium and vanadium.

4. The influence of boron on hardenability and notch toughness (Charpy Impact V-notched specimens) varied with the base composition of the steels, the composition of the intensifiers and the amount of boron present.

5. The addition of small amounts of boron was often beneficial to notch toughness at room temperature when the steels were fully hardened and tempered at low temperatures.

6. The presence of boron, especially in relatively high additions with intensifiers containing titanium, was usually either without effect or was detrimental to notch toughness at room and sub-zero temperatures when the steels were fully hardened and then tempered at relatively high temperatures.

7. The notch toughness of many of the steels was not affected appreciably by a change in test temperature from 70°F to -94°F if the steels were fully hardened and then tempered at 1000°F.

8. The hardenability of many of the experimental steels prepared in an induction furnace, and all of the steels comprising a basic open hearth heat, was markedly improved by additions of boron. However, no definite correlation was found between the hardenability effect and the amount of boron added or retained in the steels. In many of the experimental steels the optimum hardenability was obtained with small additions of boron (0.001 percent or less retained) while in
other steels the hardenability increased continuously with increase in boron. In other steels the addition of boron either as a simple or complex ferro-alloy or intensifier was without effect on hardenability. In general, relatively small additions were more effective than large; the complex intensifiers were more effective than the simple ones; and the improvement in hardenability was not so critically dependent upon the amount present when complex instead of simple intensifiers were used.

9. For the commercial steels, the magnitude of the hardenability effect was independent of the amount of boron added and the composition of the ferro-alloys used for the additions.

10. The effectiveness of boron in improving hardenability of the experimental steels increased with the amounts of elements that conferred deep hardening properties, such as manganese, chromium and molybdenum.

11. The magnitude of the hardenability effect due to boron appears to depend upon the form in which the boron exists in austenite, not necessarily upon the total amount present.

Lean-Alloy Steels

With the accelerated use of steels in the war, industry was faced with the necessity of conserving the alloying elements commonly used to confer special properties in steels. Accordingly, the American Iron and Steel Institute promulgated a series of specifications for "lean-alloy" steels, known as the NE steels. This group of steels, the 8000 series, was soon supplemented by the 6000 series, which used even smaller proportions of alloying elements. The need for knowledge of the properties of these steels was imperative in order to insure their proper utilization.

At the request of the Bureau of Aeronautics, Navy Department, a study was undertaken by S.J. Rosenburg in 1942 of the critical temperatures, cleanliness, grain size, hardenability, and mechanical properties (tensile, hardness and impact) of representative steels of the NE 8000 series. The results showed that the steels under study were capable of developing properties comparable to those of the steels which they were intended to replace. A report summarizing the test properties of all the steels studied was submitted to the Bureau of Aeronautics together with charts giving recommended heat treatments.

Heat Treatment and Impact Strength

The AISI type 431 stainless steel, containing nominally 18 percent chromium and 2 percent nickel, is capable of being heat-treated to high strengths. Because it combines strength with corrosion resistance, it is used in certain highly stressed parts of aircraft structures. Such usage demands toughness in a steel as well as strength, and in many instances failures had occurred in fittings fabricated of 18-2 stainless steel, which indicated lack of toughness. A study of the effect of heat treatment upon the impact strength of this type of stainless steel was initiated for the Bureau of Aeronautics, Navy Department, in 1940.

Toughness of the test steels was evaluated by means of notched-bar impact tests carried out over a temperature range of 88° below zero to 100°F. These tests were made on 3 different heats of steels given various quenching and tempering treatments, and were supplemented by hardness tests and exhaustive metallographic examinations. It was found that this type of steel appeared to be highly individual with regard to its tendency toward toughness or brittleness, and it was believed that these differences were caused by variations in manufacturing processes not known to the testing laboratory. Optimum heat treatments were recommended as follows:

A. For Class I material (175,000 pounds per square inch tensile strength) oil quench from 1870°F to 1900°F; temper twice at 600°F to 850°F.

B. For Class II material (115,000 pounds per square inch tensile strength) oil quench from 1,800°F; temper at 1,200°F.

These heat treatments were found useful in improving the toughness of this class of steel. The tests also showed that this steel
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is extremely brittle when tempered at certain temperatures. Tempering should never be carried out between 800° and 1,100°F.

Stabilization of Austenitic Stainless Steels

The austenitic stainless steels containing nominally 18 percent chromium and 8 percent nickel (commonly referred to as 18-8 stainless) are susceptible to intergranular embrittlement after exposure to certain elevated temperatures. Steels so treated are in a "sensitized" condition. Although such sensitization has no immediate injurious effect upon the steel, subsequent exposure to various corrosive media induces intergranular embrittlement. This type of steel is widely used in aircraft power-plant accessories and is consequently subjected to elevated temperatures and the corrosive action of exhaust gases.

The most effective method of eliminating susceptibility to intergranular embrittlement involves the addition of certain elements to the steels, which in conjunction with certain heat treatments, renders the steel immune to this type of failure. The elements commonly used are titanium and columbium. Because of conditions resulting from the war, the Bureau of Aeronautics was forced to change its specifications for this type of steel, increasing the maximum content of carbon and decreasing the minimum contents of titanium and columbium. In order to determine whether these revised specifications were satisfactory, and to evaluate the various factors influencing the stabilization of 18-8 steels, the Bureau of Aeronautics in October 1943 requested that a study be made of this problem. The resulting investigation has developed into a large-scale post-war project of considerable importance.

Experimental steels varying in carbon, titanium, and columbium were melted and fabricated for test purposes. The effect of various thermal treatments and variations in composition upon the susceptibility to intergranular embrittlement as developed by exposure to a boiling aqueous solution of sulfuric acid and copper sulfate is being studied, and this study is being supplemented by metallographic examinations. Data secured to date indicate that the minimum contents of titanium and columbium (minimum titanium equals 4 times percent carbon, and minimum columbium equals 8 times percent carbon) allowed by the revised Navy specifications are insufficient to confer immunity to intergranular embrittlement, and that these minimum ratios should be 5 and K, respectively. The increase in the allowable maximum carbon content (0.10 percent) is without effect in steels having the same ratio of titanium to carbon, or of columbium to carbon. The test data also showed that in the acceptance test prescribed by the Navy specification the sensitizing temperature (1200°F) is too high to develop maximum susceptibility to intergranular attack. A lower temperature (incomplete data indicate 1030°F, although a somewhat higher temperature than this may be more suitable) in conjunction with longer time at that temperature, is more effective in inducing susceptibility to intergranular embrittlement. Five reports on this subject have been submitted to the Bureau of Aeronautics.

Chromium Plating and Endurance

Chromium plating is coming more and more to be used in salvaging worn steel parts and in some cases to building up steel parts that were inadvertently machined to dimensions too small for the planned use. If such plated parts are subjected to alternating stresses the chromium plating may lead to early failures from progressive or fatigue failure. At the request of the Bureau of Aeronautics, R. L. Logan at the NBS investigated the effect of chromium plating on the endurance limit of some of the steels used in aircraft. This included the effect of chromium plating on steels of different hardness, different plating thicknesses on the same steel, plating the same steel at different rates (i.e., current densities), and baking the steel after plating. Endurance tests were made in the R. R. Moore notched-beam fatigue-testing machines.

It was found that the endurance limit of all steels was reduced to some extent by chromium plating and the harder the steel the more the endurance limit was reduced by a given plating technique. There seemed to
be no linear relation between plating thickness and the endurance limit. However, with the harder steels the endurance limit of steel plated to a thickness of 0.008 inch was less than that of the same steel plated to 0.004 inch. It was found that the endurance limit could be significantly increased by baking at the proper temperature. This procedure for increasing the endurance limit permits the design and construction of lighter aircraft of the same strength.

**Decarburization of Tubing**

An investigation on the decarburization of seamless tubing of NE 8630 steel was supervised by T. G. Digges with the cooperation and financial support of the Office of Production Research and Development, War Production Board. The NBS was requested to make a survey of the existing methods for determining the decarburization of steel, with special attention directed to the development of a nondestructive and quantitative method suitable and useful to the tubing industry, and to determine the effects of decarburization on the tensile properties of seamless alloy tubing used for aircraft.

Decarburization of seamless steel tubing may occur during hot working, normalizing, annealing, and other heat-treated operations. The present general practice of the producers is to carry out some of the thermal treatments in a protective atmosphere, but it is not feasible to use protective atmospheres during each step necessary for the formation of a tube from a solid billet. Decarburized zones, therefore, are to be expected at both the inner and outer surfaces of seamless steel tubes of low-alloy content after some of the steps used in processing. In many applications of tubing these decarburized surfaces do not materially affect the life, whereas in other applications it is mandatory to have at the surface the maximum properties that are attainable in the unaffected zone or base composition of the steel. Since no method for measuring decarburization has been selected or adopted as a standard, disputes often arise between producers and users of tubing as to the extent of these zones.

At the present time, NE 8630 steel is widely used for producing light seamless tubing for aircraft. This material is commonly furnished to the users in the normalized or stress-relieved condition. It was decided, therefore, to confine the work primarily to a study of round seamless tubing of a constant outside diameter (1 inch) with three different wall thicknesses (0.036, 0.065, and 0.096 inch) processed from NE 8630 steel to conform to the requirements as set forth in Army-Navy aeronautical specifications. Tests were carried out to determine the suitability of various methods for evaluating the decarburization of the tubing in the structural condition as received from several producers and users, as heat treated for varying degrees of decarburization; and the effect of decarburization on the tensile properties of the tubing as normalized and as heat-treated (quenched and tempered).

The method investigated for evaluating decarburization included microscopic examination of polished and etched cross sections; chemical analysis for carbon on samples prepared by making consecutive cuts 0.001 to 0.002 inch deep starting at the surfaces; hardness surveys on fully quenched specimens; and magnetic analysis.

The evaluation of decarburization by carbon analysis was considered to be the most accurate of the various methods investigated. However, this method is limited primarily to laboratory use. Hardness values obtained with the Rockwell superficial tester on fully quenched tubing were indicative of the carbon content of the surfaces, but hardness testing does not appear to be well suited for determining the depth of decarburized zones at the inner and outer surfaces of tubing. No correlation was found between the magnetic properties and decarburization of the tubing as received. The evaluation of decarburization of seamless tubing microscopically appears to be the method best suited for use commercially. Although the values obtained by this method varied with the structure of the tubing, sufficiently accurate measurements at 100 diameters were obtained on specimens with structures consisting of spheroidized cementite, pearlite,
and ferrite or martensite-tempered martensite.

The yield and tensile strengths of the tubing as normalized or as quenched and tempered increased appreciably with increase in depth of decarburization, whereas the elongation was not affected for the range of decarburization investigated.

An important fact brought out by the study was the absence of decarburization in many of the tubes as received. If this condition is representative of the quality of the tubing supplied by the producers, it would seem that, from the viewpoint of the users, decarburization of seamless tubing of NE 6830 steel as received is not a particularly difficult problem in many of its applications in the construction of aircraft.

**Aluminum Alloy**

**Artificial Aging**

The aluminum alloy most generally used for wing and fuselage coverings in aircraft has been the 24ST aluminum alloy (4.5 percent Cu, 1.5 percent Mg, 0.6 percent Mn). It was recently shown that the yield strength (a property much used in design) can be increased 20 to 25 percent by artificial aging of the material, after the usual commercial heat treatment at temperatures of 350°F to 400°F. It was known that overaging would produce a decrease in the desired properties. It was desirable, therefore, to choose a temperature at which the desired properties would be obtained in a relatively short time (say 6 hours or less) so that all of the material in a batch would have the benefit of the aging treatment and at the same time any material which came up to temperature almost at once would not be overaged in the total time in the furnace (say 10 to 12 hrs.). It was also desirable to know the effect of the aging period and temperature on the resistance of the material to corrosion.

At the request of the Bureau of Aeronautics, Navy Department, H.L. Logan of the NBS made a study of various aging periods on the tensile properties of the commercially heated alloy, at temperatures of 350°, 375°, 385°, and 400°F. The resistance of the material to stress-corrosion cracking in the \( \text{H}_2\text{O}_2 + \text{NaCl} \) solution was determined in the laboratory, and resistance to a marine atmosphere was determined for some of the specimens in stress corrosion racks at Hampton Roads.

**Beryllium Alloys**

The low density of beryllium makes it an attractive metal for use in the field of aviation engineering, but its brittleness and lack of workability prevent its use for such purposes. The possibility that the addition of beryllium to aluminum might produce an alloy superior in properties to either metal alone had been investigated previously. However, difficulties in melting and casting the beryllium-aluminum alloys had limited the production to small ingots. The properties of test specimens from these small ingots offered sufficient promise to warrant investigation of the possibility of producing beryllium-aluminum alloys in the sizes necessary for the production of engine parts such as forged pistons. This was undertaken at the NBS by J. G. Thompson at the request of the National Research Council.

Sixty-one beryllium-aluminum ingots were produced in the course of the investigation. Their production permitted study of the following variables on the soundness and workability of the ingots: (1) Variation in beryllium content, from 10 to 35 percent; (2) effect of melting and casting in vacuum, in helium, and in air under various fluxes; (3) effect of additions of copper, magnesium, silicon, silver, zinc and zirconium, singly and in combination; (4) use of plumbago, graphite, and magnesia crucibles; (5) use of steel, sand, and composite molds; (6) effect of rate and temperature of pouring; (7) effect of temperature and shape of mold.

The possibility of obtaining shapes of suitable size by electric welding also was investigated.

The results confirmed the previously expressed opinion that the casting of beryllium-aluminum alloys presents unusual difficulties which increase with the size of the casting and with increase in the beryllium
content. The difficulties result from the long solidification range of the alloys and the limited solubility of beryllium in aluminum.

Casting difficulties were not eliminated by melting in vacuum or in helium or by numerous variations in the details of melting and casting in air. The best results in the casting of 8-pound ingots of 30 to 35 percent beryllium content were obtained by very slow pouring to approximate progressive solidification of the ingot from the bottom upward, thereby minimizing shrinkage troubles. Certain of these slowly poured ingots were satisfactorily sound according to macrographic, micrographic and radiographic examination. Additions of titanium as a degasifier appeared to have some merit, but the beneficial effect of such additions was less important than the benefits derived from slow pouring. The best of the ingots could be worked only to a limited extent indicating that the production of sound ingots did not insure the production of forgeable ingots.

Elastic Properties of High-Strength Metals

In the design of structures and machines, it is necessary to know how much stress may be applied without crossing the boundary between elastic and inelastic deformation. If this boundary is crossed in service, the structure does not return to its original dimensions on removal of stress, but is permanently deformed. It may even fail completely, with disastrous results. For structures and machines that are to be used on the ground, it is often possible to design with a considerable "factor of safety" by making the sections larger, but in airplanes the "factor of safety" must be reduced so as to save weight. It therefore becomes necessary to know exactly the boundary between elastic and inelastic deformation, and to know how much plastic deformation is caused by slight increases of stress beyond the limits of elasticity. This requires careful investigation of the relation between stress and strain.

An investigation of the deformation of metals within their working ranges of stress was started before the war at the NBS, sponsored by the NACA. The work was supervised by D. J. McAdam. The indices selected to define the action of a metal under applied stress were: (1) The proof stresses producing selected amounts of permanent set, namely, 0.001, 0.003, 0.01, 0.03, and 0.1 percent; (2) the modulus of elasticity; and (3) the variation of the modulus with stress. This variation can be expressed either by the stress coefficient of the modulus, or by the moduli at both zero and elevated stress. These properties were measured in tension and in shear upon a number of high-strength ferrous and nonferrous metals and alloys.

The properties selected were correlated with the degree of cold work or plastic deformation and with annealing or tempering temperature. From these results, and from studies of work of other investigators, the variation of these properties with plastic deformation or heat treating temperature could be explained as due to variation in relative dominant influence of the following fundamental factors: (1) Macroscopic internal stress, (2) the "work-hardening" or "lattice-expansion" factor, and (3) crystal orientation.

The method of evaluating these properties consists essentially in the simultaneous measurement of stress, strain and permanent set upon a specimen under a predetermined loading schedule, and thereafter calculating the properties from "stress-deviation" and "stress-set" curves plotted on appropriately sensitive scales.

The first phase of this project consisted in determining the effect of plastic deformation upon the tensile elastic properties of 18-8 Cr-Ni steel of varying compositions and degree of cold work. An extensive study was made of the effect of loading rate, and of rest interval after plastic deformation, upon tensile elastic properties. A study also was made of mechanical hysteresis, as obtained by cyclic loading and unloading.

Later work consisted in determining: (1) The effect of plastic deformation and heat treatment upon tensile elastic properties of typical stainless steels and nonferrous metals, including tests at sub-zero temperature (-110°F); (2) the shear elastic
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properties of 18x8 Cr-Ni steel and non-ferrous metals as affected by plastic deformation and annealing temperature; (3) Poisson's ratio for 18x8 Cr-Ni steel, as influenced by plastic deformation and heat treatment derived from tensile and shear elastic measurements; and (4) the tensile elastic properties of nonferrous metal tubing upon which the shear elastic properties had been derived previously.

The most important conclusions are listed below:

1. An incomplete view of the elastic properties of a metal is obtained by considering either the stress-strain or stress-set relationship alone. Consideration should be given both relationships.

2. Positive and negative creep occur during or following raising or lowering the stress upon a metal specimen, even when well within the elastic limit of the metal.

3. Successive stress-strain or stress-set curves upon a single specimen of a metal give elastic property values which are greatly affected by the intervening rest intervals. Plots of elastic properties versus plastic extension as obtained by this method therefore give gradual wavelike "basic" curves upon which are superposed fluctuations due to varying rest interval.

4. The variations of such basic curves are determined by the relative dominant influence of macroscopic internal stress, lattice expansion and crystal orientation.

5. For all metals an increase of macroscopic internal stress tends to lower the several proof stress values and to decrease the modulus of elasticity and the slope of the stress-modulus curve. There is some evidence of directional influence of the induced internal stress; it differs when induced by plastic extension from that induced by plastic shear.

6. An increase of lattice expansion, which accompanies the increase of "micro structural" type of stress induced by work hardening, tends to lower the modulus of elasticity and to increase the several proof stresses. No directional influence due to the method of cold work was observed.

7. Preferred crystal orientation, as obtained in some metals after plastic deformation, has considerable directional influence upon both tensile and shear moduli of elasticity of many of these metals.

8. Owing to differences in variation of the tensile and the shear moduli with cold work, or with annealing temperature, correspondingly large variations of effective values of Poisson's ratio are obtained.

9. When the several proof stresses, the modulus of elasticity, and variation of the modulus with stress have been evaluated for a metal, a fairly good picture is obtained of the action of that metal under applied stress.

Airplane Firewall Materials

Because of the critical shortage of chromium-nickel stainless steel, a satisfactory substitute for stainless steel sheet was sought for use in the firewalls in airplanes between the engine and the cockpit. Low-carbon steel sheets, with thin surface coatings of aluminum, stainless steel, zinc, or zinc and nickel, and low-alloy steels containing 5 percent of chromium or 1 percent of silicon were selected for investigation by W. H. Mutchler.

Samples were heated, both by an impinging flame and in an electric furnace for periods of 2 1/2, 5, 15 and 60 minutes, at intervals of 100 degrees, from 1,000° to 2,000°F. Samples also were repeatedly subjected to actual fires, started in an airplane engine and usually extinguished within 30 seconds. The maximum temperature of these fires was approximately 1,700°F. The effect of the heating upon the tensile properties and the microstructural characteristics was determined for each material. It was concluded that either the stainless-clad or aluminum-coated steels would prove most satisfactory for use in airplane firewalls, and that all the metals investigated would withstand fires of high temperatures for periods up to 15 minutes without failure.

The NBS was not informed regarding the extent to which these findings were utilized in practice. It is understood, however,
that aluminum-coated low-carbon steel firewall walls were used in the manufacture of some aircraft. It is believed, also, that the anticipated shortage of chromium-nickel stainless steel did not become sufficiently critical to make mandatory the use of suitable substitutes for airplane firewalls.

**Low-Tin Solders**

It was realized at the very beginning of the war that it was absolutely essential to stretch our meager tin reserves to the limit. As the solder industry was the second largest consumer of tin, it was necessary to curtail drastically the use of tin for this purpose in order to make conservation measures effective. As the result of conservation orders and emergency specifications, low-tin solders were forced on the market with little or no information regarding their properties or how they should be applied. These solders were immediately condemned by many mechanics as weak, sluggish, worthless, and wasteful.

Accordingly, a project was undertaken by S. K. Gutterman at the NBS to determine the properties of low-tin solders and soldered joints and provide information regarding the procedures necessary for making satisfactory joints with the low-tin solders. Thirteen lead-base solders ranging in tin content from 0 to 50 percent and 15 soldering fluxes were investigated. The melting ranges of the solders were determined, and the most suitable temperatures for applying them ascertained. Joints of different types (single-lap, double-lap, scarf, butt, and plug and sleeve) were made with brass, copper, and mild steel. The strengths of these joints and the ability of the soldering fluxes to promote spreading of the different solders on these materials were also determined.

It was found that when the proper techniques were used there was very little difference in the shear strength of joints made with solders containing 15 percent or more tin. In fact, the strength of joints made with solder containing less than 3 percent of tin was only about 20 percent less than that of joints made with the conventional prewar 50-50 lead-tin solder. Although satisfactory joints can be made with all the solders investigated, it must be admitted that in general more time and care are required to make such a joint with lower-tin solders, primarily because of two factors: (1) the lower the tin content the higher the melting point, and consequently the higher the temperature at which the solder must be applied; and (2) the lower-tin solders do not spread or "tin" as well as the higher-tin solders. Fluxes containing appreciable percentages of zinc chloride with minor percentages of ammonium chloride were effective in promoting spreading of the low- (as well as the higher-) tin solders.

**Fatigue Damage of Metals**

The purpose of this project was to find some way to evaluate the damaging effect of fatigue stressing of metals above the endurance limit through accompanying changes in other characteristic properties of the metal. Tests were made by J. A. Bennett to determine the effect of such stressing on the X-ray diffraction patterns and the microstructure of 28S aluminum alloy, and on the impact resistance of SAE X4130 steel and 28S aluminum alloy. These tests showed no change which could be correlated with the progress of fatigue damage prior to the start of cracks.

Damage resulting from repeated stresses above the endurance limit was evaluated by determining the decrease in endurance and the drop in fatigue limit, which involved the use of several specimens. The results showed that the rate of damage was a complicated function of the stress history, but a method was developed for measuring the damage independent of the stress. It was then possible to add the damage occurring at different stresses and thus to predict the performance of specimens under complicated loading schedules.
Welding

Armor

In July 1933, the Bureau of Construction and Repair, Navy Department, asked the NBS to develop techniques and materials for the welding of armor for naval vessels. If such fabrication could be used, there were many advantages to be gained, among which were faster erection, easier and faster repair in case of damage, and saving of weight. Armor plate of any type is exceedingly hardenable, and ordinary welding methods and materials had yielded unsatisfactory results. Medium-carbon steel and low-alloy steels contributed to underweld cracking when welded with ordinary techniques. It was possible to weld the steel with special techniques, but these were impractical from a shipbuilder's viewpoint.

It was decided to attempt to weld the armor with austenitic steel electrodes containing 18 percent chromium and 8 percent nickel, a process previously used by Krupp's in Germany for welding pressure vessels. Test welds were made at the Philadelphia Navy Yard and examined at the NBS. The process appeared to be practical from the start since strong joints could be obtained which were essentially free from cracks. Somewhat later, the use of other chromium nickel austenitic steel electrodes was investigated, and a variety containing 25 percent chromium and 20 percent nickel was adopted as a standard material for welding armor, since it provided stronger joints without loss of ductility.

The development of a satisfactory welding technique for armor was also investigated. Welds were made with various techniques at the Philadelphia and New York Navy Yards and tested at the NBS. It was found necessary to use an intermittent process since continuous welding caused a building up of stress which at some points became high enough to cause fracture of the metal. Back step pyramid and block techniques were investigated and found satisfactory for the most part. However, in critical locations the block method was found to be most satisfactory and while expensive, was nevertheless recommended for such locations. The results of this investigation were widely in the welding of armored decks of the modern naval vessels.

After welded tanks and other armored vehicles had been designed, the Bureau was asked to assist the Tank and Automotive Center of the Ordnance Department, Army, in the investigation of methods of welding tank armor. The shortages of some metals prohibited the use of the standard armor and electrodes used by the Navy, and consequently other types of armor and electrodes had to be developed.

The problem was handled by the metallographic examination and mechanical testing of samples of welded armor plates ballistically tested at the Aberdeen Proving Grounds. Hundreds of specimens welded in the tank manufacturing plants were tested in this manner, and the results were of great assistance in the selection of four general armor compositions and the development of satisfactory techniques for welding them.

Considerable assistance was also given to the Tank and Automotive Center in the development and ultimate adoption of specifications for electrodes to be used in the welding of armor. Many samples of armor plates welded with different types and compositions of electrodes with different types of coatings were examined in this part of the program. In order to keep the program as practical as possible, all test welds were made in the tank plants under actual manufacturing conditions on armor which had previously passed ballistic tests.

G. A. Ellinger was in charge of this work. He was also the NBS representative on the subcommittee on the Welding of Armor, Ferrous Metallurgical Advisory Board, Ordnance Department.

Structural Steels

The research work on the welding of naval structural steels started long before the war. In the shipbuilding program of the Navy beginning late in 1933, the use of a high-tensile low-alloy steel was greatly desired for the structural members of naval vessels. Such a steel should have high strength and be weldable under all conditions of shipyard practice without recourse to special welding methods or techniques. The desired
yield strength of the unwelded base plate was 50,000 lbs per sq.in., and the ultimate strength 70,000 lbs per sq.in. The possible saving in weight by the use of such steel was obvious.

The program as laid out was to consist of the testing of welded joints made in all low-alloy high-tensile steels produced commercially at that time. However, a satisfactory weldability test was not in existence. Several standard tests were tried, none of which proved to be suitable or reproducible enough. Subsequently, the tee bend test was devised and perfected. It was found to be reproducible and satisfactory for use in the comparison of welded samples of steels. Numerous proprietary steels and other specially developed steels were tested, and as a direct result the Navy Department specified a manganese-vanadium steel for use in structural members of naval vessels.

Later the shortage of vanadium necessitated a modification in the composition of the high-tensile steel. The substitute steel was not as satisfactory for ship construction, and considerable difficulty was encountered in its use. Many tests were made by G. A. Ellinger and M. L. Williams to try to modify this composition so that it could be easily welded and the construction made more nearly fool-proof. During this period numerous visits to ship-building yards were required to assist the personnel in the solving of problems connected with the welding of this steel. Ultimately a new specification was drawn up which included the old type manganese-vanadium steel and a new type of low-alloy steel containing small amounts of vanadium and titanium. At the present time these steels are being used satisfactorily. This problem was extremely formidable because of the vast tonnages involved and the necessity for fool-proof construction.

The Army Engineer Board, also requested assistance in the selection of low-alloy steels of weldable quality for use in welded bridges and other engineering equipment. Numerous tee bend tests of steel were made and assistance given in the writing of a U.S. Army specification. The original specification included three compositions of steels which were found to be satisfactory in tests. Since that time several other compositions have been included as a result of the tests.

Vessel Hull Steels

Early in 1943, the fracture of deck and hull plates of merchant vessels became a serious problem. The Secretary of the Navy appointed a board to investigate the design and constructions of welded steel merchant vessels. This Board requested that the NBS assist in the investigation of the fractured plates from these vessels in order to determine the cause and to suggest a remedy.

Following that request, fractured plates from approximately 30 merchant vessels were investigated. Many failures originated in welds, particularly in highly stressed areas, most of which had been inadequately designed. In most of these cases the weld in which the initial fracture occurred was defective. However, the fracture after originating in the weld generally did not continue in the rest of the weld but entered the steel plate and progressed in a brittle or cleavage type of fracture. Investigation of these fractures has invariably pointed out that these steels were notch-sensitive and that cracks once started generally progressed entirely across the plate, the crack itself acting as a notch for the propagation of the fracture.

Corrosion

Stressed Specimens

Marine atmospheric exposure of aluminum or magnesium alloys most nearly represent the severe service conditions to which the material in a finished aircraft may be subjected. Therefore, tensile specimens from various aluminum and magnesium alloys were subjected to stress-corrosion tests in a marine atmosphere at Hampton Roads, Virginia. Stresses were applied by means of lever systems, and unstressed specimens were mounted
adjacent to the stressed specimens so that the effect of stress in the corrosive environment could be evaluated. Aluminum specimens were removed after exposure periods of 45 to 90 days and were broken in tensile test to determine the losses in tensile properties. Magnesium alloys were permitted to run to failure in order to obtain the relation between stress and time required to result in failure. The time necessary for failure was determined both in the laboratory and in the atmospheric exposure racks by electrically-operated solenoid counters connected in series with switches which were pulled by the weight of the levers when the specimens broke. The solenoid counters were activated once every 6 minutes (10 times per hour) by means of a suitable time switch. The results of the weather exposure tests have generally confirmed the results of laboratory tests and have shown that the aluminum alloys introduced during the war are resistant to stress corrosion.

Whenever a new aluminum alloy is offered for aircraft construction, one of the first questions to be answered is whether or not the material is susceptible to stress-corrosion cracking in a marine atmosphere. Any testing of materials in a marine atmosphere is time-consuming. Fortunately, there are laboratory tests that will indicate in a short time whether or not aluminum alloys are susceptible to stress-corrosion cracking. During the war, three new aluminum alloys were introduced for use as sheet material in aircraft structures. These materials were tested at the NBS using improvements on older laboratory methods to determine their resistance to stress-corrosion cracking before they were accepted for use by the Navy Department in aircraft structures.

The resistance to stress-corrosion cracking of aluminum alloys containing appreciable quantities of zinc was determined in a boiling sodium chloride solution. Specimens were stressed by bowing. This method of determining stresses was developed at the NBS during the war. The stresses were computed from the chord-to-arc distance (determined with a dial gage reading to 1/10,000 inch), the thickness of the material, and Young's modulus for the material. Stressed specimens were placed in wide-mouthed flasks equipped with reflux condensers to prevent evaporation during boiling. Laboratory tests indicated that the aluminum alloys introduced during the war were resistant to stress-corrosion cracking and that properly-aged 24ST aluminum alloy was generally as resistant to stress-corrosion cracking as the unaged material.

**Aircraft Fittings**

It has been considered necessary from a structural point of view that steel bushings or bearings used in aluminum-alloy aircraft fittings should be made oversize and forced into the fitting. Because stresses were thus set up around the bushings, it was considered very probable that in corrosive media the aluminum-alloy material adjacent to the bushing would be liable to stress-corrosion cracking. At the request of the Bureau of Aeronautics, Navy Department, the NBS made a series of laboratory studies of the resistance of fittings to the combined action of stress and corrosion. By means of lever systems these fittings were stressed with dead loads up to 50 percent of the breaking load for the fittings, in a NaCl+H₂O₂ corrosive medium. The results showed that while the use of oversized bushings or bearings reduced the resistance of the fittings to the combined action of stress and corrosion, the damage was not great as had been expected.

**Salt Spray and Corrosion Testing**

The salt-spray test has been used for over 20 years at the NBS as a corrosion test. It is employed principally to determine the behavior of materials and protective coatings intended for use under seacoast conditions, though sometimes it is used as an accelerated test for determining some specific property, such as porosity of coatings, corrosion resistance of materials or the effect of galvanic coupling of materials. During the past war, immense quantities of metallic materials were used on shipboard and at shore installations, sent overseas and stored under marine exposure. Huge volumes of materials were unloaded in the water, gathered
in and stored on beaches under most severely corrosive conditions. Since salt spray as a laboratory test best simulates these exposure conditions, it was selected by the various agencies concerned to serve as a guide and check in both development work and routine testing. Work was undertaken by L. J. Waldron on the quality and uniformity of protective coatings on metals for the purpose of developing specifications.

Approximately 5,000 samples were submitted (1942-45) by various war agencies for tests with one or more of the following objectives in mind: (1) Effectiveness of the protection of metallic or nonmetallic coatings on parts or assemblies exposed to marine conditions (approximately 2,600 items); (2) effect of exposure upon operational characteristics of parts or assemblies (approximately 2,000 items); (3) actual resistance of parts or assemblies to salt-spray corrosion (approximately 600 items).

Major items of these submittals included food cans; helmet parts; bearings; valves; optical parts; lifeboat, aircraft navigation, and field equipment; electrical instruments; depth-charge pistols; firing mechanisms; proximity fuses; metal panels; mirrors; and miscellaneous equipment. The requests came from the Army, Navy, Maritime Commission, Coast Guard, and the NBS Ordnance Development Division.

Actual service experience, supplemented by spray tests, showed that iron or steel parts or assemblies must be protected by suitable metallic or organic coatings, or both, if they are to withstand exposure to salt water conditions. Emulsions, waxes, and allied types of coatings are, by themselves, inadequate. The development of synthetic coatings, the use of inhibiting primers, and careful application and drying techniques helped solve many of these problems. Emphasis was placed on the avoidance of unfavorable metal combinations and on the proper insulation of electrical circuits.

Numerous materials which had deteriorated through corrosion were submitted by various war agencies for examination to determine either the extent of damage, causes of corrosion, or corrective means of mitigating the corrosion. Supplementary corrosion tests were frequently required.

Numerous cases were encountered by the Army in the early part of the war where food (in cans) was spoiling in storage in this country. Investigation of these conditions, together with extensive laboratory tests, revealed that condensed moisture on the cans in combination with volatile compounds from the fibre board containers was responsible for corrosion of the cans. Elimination of these conditions appears to have solved the problem.

Frequent failure of electrical systems on naval aircraft through short-circuiting of connectors resulted in a laboratory investigation of the causes. It was found that the use of acid fluxes in soldering in combination with condensed moisture would result in sufficient corrosion to cause short-circuiting. Elimination of these fluxes and precautions to exclude moisture were recommended. Failure of miscellaneous parts used on shipboard and aircraft was found to be due generally to incorrect use of materials, galvanic coupling of metals, insufficient protection of parts, or presence of severe or incorrect operating conditions.

Corrosion of Ordnance Material

In all small arms and in most artillery up to 5-inch guns, cartridge cases are used. The consumption of brass for this purpose was enormous, because it was necessary to produce and store in many locations millions of rounds of ammunition. This consumption of brass soon resulted in a shortage of copper. The scarcity of copper led to intensive studies which resulted in the production of steel cartridge cases having the required physical properties. It was, however, necessary to protect the steel cases against corrosion during storage and transportation. During 1942, the NBS received numerous requests from the War and Navy Departments for information and advice on protective coatings for this purpose. In December 1942,
William Blum was appointed a member of the Advisory Committee to Frankford Arsenal on this subject. Under his direction studies were made at the Bureau on this and related problems.

The two types of coating on the steel cases that proved most promising were electroplated zinc and a baked phenolic varnish. The zinc coating prevents the steel from corroding even where it is exposed through scratches, but in humid or saline atmospheres the zinc acquires white corrosion products that may interfere with extraction of the fired case. The varnish coatings furnish good protection so long as they are intact and continuous, but permit local corrosion of any steel that is exposed by scratching or chipping.

To retard corrosion of the zinc, treatments in chromate solutions, (e.g., the "Cronal" process of the New Jersey Zinc Company) have been successfully applied. The first research involved the preparation of flat steel panels by plating with zinc in different types of bath, and applying films by different chromate and phosphate processes. Exposure to salt spray and to the atmosphere in Washington, D. C. and Philadelphia, Pa., showed that all zinc coatings of a given thickness are about equal in protective value, and that chromate films are more effective than phosphates regarding corrosion of the zinc.

Because it is frequently desirable to apply paint over zinc-coated steel, either for appearance or for additional protection, a study was made on that subject. It was found that on hot-galvanized steel, pre-treatments with phosphate solutions (e.g., the "bonderizing" of the Parker Rust Proof Company) improved the adhesion of paints more than did chromate treatments. On zinc-plated steel the phosphate and chromate treatments were both beneficial, but less necessary than on hot-galvanized steel. On each type of zinc coating, use of a zinc-chromate primer prior to the final paint coating was advantageous.

In order to obtain direct evidence on the performance of steel cartridge cases with different finishes, several thousand rounds of Army and Navy 20 mm and Navy 40 mm ammunition were loaded using (a) brass cases, (b) steel cases coated with zinc and Cronal, or (c) steel cases coated with a baked varnish. These loaded rounds were subjected to salt spray for 100 or 200 hours and to immersion in aerated salt water for like periods, corresponding to very severe exposures on deck or when actually submerged in sea water.

Proving ground tests showed that all types of cases, even after severe corrosion, can be fired successfully if, as is customary with 20 mm rounds, the cases are lightly oiled before firing. The application of a wax film does not prevent corrosion, but it results in less adherent corrosion products. The tests disclosed considerable leakage of salt water into the cases that had been sealed at the mouth with only a four-point crimp. The zinc-plated cases showed less leakage, possibly because initial corrosion products sealed the joint.

**Gun Barrel Erosion**

The increased velocities and rates of fire of modern rifled guns have resulted in such rapid erosion and failure of the gun barrels that decided improvements were necessary to secure any adequate life of the guns. The design and improvement of high-velocity, rapid-fire guns was the major project Division One of NDRC, and of the Geophysical Laboratory of the Carnegie Institution of Washington, a contractor for NDRC.

Early in 1942, the NBS was requested by the Geophysical Laboratory to cooperate in a study of plated coatings to retard erosion of gun barrels. The services of about 15 persons, directed by William Blum, were devoted to this project, which included active cooperation with the Geophysical Laboratory, Franklin Institute and Army Ordnance, and frequent contacts with other contractors of Division One, NDRC.

Chromium plating was tried out in caliber-0.30 barrels at Frankford Arsenal before 1928; and has been applied in production to large naval guns at the Washington Gun Factory since about 1928. In each case coatings less than 0.001 inch thick were applied,
which yielded a relatively small increase in gun life. Observations on such deposits showed that they were cracked and porous and permitted erosion of the underlying steel.

The Bureau's principal efforts were devoted to improvement in the properties of the chromium, and to an increase in its thickness. The ordinary chromium deposits, used for ornament and for wear resistance, are usually produced at about 50°C (122°F) and 20 amp/dm² (300 amp/ft²). They are very hard and brittle, contain small cracks, and contract by as much as 1 percent when heated, e.g., to 700°C (1,300°F). It was found that chromium deposited at 85°C (185°F) and 40 to 120 amp/dm² (370 to 1,110 amp/ft²) is relatively soft and less brittle (but not ductile); has few cracks; and contracts only about 0.2 percent when heated. The latter type has been designated "low contraction," LC; and the former "high contraction," HC chromium.

Chromium plating of both nitrided and stellite liners barrels was approved by the War Department, and was conducted commercially by the Doehler-Jarvis Corporation with whom the NBS cooperated. By V-J day, several plants were installing equipment to conduct plating of caliber-0.50 barrels. Further studies on the applications of chromium to guns of other calibers and types are still in progress.

Stellite breech liners are valuable because this alloy has a high "hot-hardness," that is, it remains relatively hard at the high temperatures that may be reached near the breech. Because electrodeposition of a suitable coating may be more convenient and more economical than the use of a solid alloy, studies were made on the deposition and application of alloys of tungsten or molybdenum with iron, nickel, or cobalt. New types of baths were developed and deposits with favorable properties were obtained.

**Aircraft Sheet Metal**

This investigation by the Division of Metallurgy has had, for its main objective, the accumulation of fundamental data on the corrosion of metals used in aircraft, particularly of the light-metal alloys of aluminum or magnesium and of stainless steel sheets, and has been carried out under the joint sponsorship of the NACA, the Army Air Forces and the Bureau of Aeronautics, Navy Department. It has been in progress continuously since 1933, and as each new experimentally developed alloy reached the stage of semi-production it was included in the program for comparison with commercially available alloys.

The work involved determining the effect upon corrosion of such factors as chemical composition, fabrication, heat treatment, aging, chemically or electro-chemically applied surface treatments, protective paint coatings, contacts with dissimilar metals and joining methods (riveting, welding, steel stitching). The exposure panels were tested by laboratory corrosion processes (salt spray, intermittent or continuous immersion in suitable electrolytes); by weather exposure to inland rural conditions (Washington, D. C.); temperate marine conditions (Hampton Roads, Va.); tropical marine conditions (Coco Solo, Canal Zone); or by repeated immersions in sea water (tidewater racks at Hampton Roads). Whole assemblies, such as airplane wings were frequently included in the outdoor tests.

The materials investigated included all the commercially and experimentally available alloys of aluminum, magnesium, and stainless steels, more especially those in sheet form. An alloy developed by the Japanese and obtained from captured enemy aircraft was also investigated.

The results obtained are too numerous and specific in their nature to be effectively summarized but are available in numerous papers, published for the most part by the National Advisory Committee for Aeronautics, with restricted distribution during the war. A bibliography of the pre-war publications appears in the Bureau's Journal of Research, 25, 75 (1940).

A few of the pre-war findings emerging from these investigations may be considered of major importance in contributing to the war effort. Among these are the experiments which led to the commercial development of "Alclad" materials for use in airplanes; the development of correct methods for heat-treating of aluminum alloys of the
duralumin type for rendering them immune from the intergranular type of corrosion; and the method for the anodic treatment of aluminum alloys, in 10 percent chromic acid electrolytes, now included in the Army-Navy Specifications. The information accumulated was of value to the sponsors in permitting the quick solution of many specific corrosion problems which originated during the war, particularly with respect to recommendations for the metals to be used in new equipment for military use.

Some miscellaneous tests, closely related to the investigations, were conducted on request to solve specific problems. One, for example, had to do with determining the suitability of drift signal powders used in "spotting" areas for identification on the ocean by dropping the powders from aircraft. This work established the superiority of chrome-yellow and fluorescein powders over bronze powders. The latter powder, when unavoidably split onto the metal plane parts, would cause rapid corrosion, while the two others were demonstrated to be harmless in that respect.

Miscellaneous Metallurgical Projects

Fineness of Powders

The problem of measurement of the fineness of sub-sieve powders was met with in a number of instances. Some interdepartmental requests were for the determination of particle-size distribution of material finer than a specified sub-sieve size. In other requests the surface area values or surface-mean diameter values were required. Inasmuch as different methods of determining fineness often fail to give concordant results, various methods were often used in order to determine which of the methods rated a series of powders in the same order of some characteristic, such as their reactivity. Fineness was studied by means of the electron microscope, the light microscope, the Andresson pipette, the Wagner turbidimeter, nitrogen adsorption, and air permeability. The work was supervised by J. Tucker, Jr.

In one instance, the Picatinny Arsenal required in their plant control work a rapid and precise method of determining the fineness of a metal powder. A special fineness apparatus was designed for this powder, patterned after the U-tube or Blaine air-permeability fineness meter. The surface area values determined on different mixtures of two gradations of the powder were within 0.5 percent of the respective mixture values calculated from the surface area values of the separate gradations. By using this instrument, only 5 to 8 minutes were required for each test, permitting adjustment in the mix if necessary.

In another instance, the Naval Ordnance Laboratory submitted a number of samples of metal powders and requested fineness tests by different methods. Nitrogen adsorption tests, electron microscope pictures, photomicrographs, sedimentation, and air-permeability fineness tests were made. The nitrogen-adsorption apparatus and air-permeability apparatus rated the fineness of the different powders in the same order. Information was received that the reaction rates of the different metal powders were in the same order as the surface area values of the respective powders when determined by the air-permeability or nitrogen-adsorption methods. This finding was of great value, because the reaction rate of the material could be determined by one quick measurement, whereas it had been assumed by those using the powders that the reaction rate was a complicated function of the grading, the determination of which required considerable time.

Welding of Nickel

During the fabrication of a complicated piece of equipment for the Manhattan District at the plant of the Mehring & Hanson Company, considerable difficulty was encountered by the failure of nickel welds in nickel tubing. The elimination of these failures was a matter of great importance and urgency. The problem was solved by the Bureau in 4 days, utilizing the results of an investigation carried out at the NBS by P. D. Merica nearly 30 years ago. Examination of the fractures showed the presence of a nickel sulfide-nickel eutectic in the grain boundaries. The source of the sulfur was traced
to hydrogen sulfide in the acetylene used for welding. The use of purified acetylene free from hydrogen sulfide was recommended, which enabled the company to finish its contract with no further failures.

**Aircraft Parts and Failures**

A great many examinations and tests have been made on aircraft parts for both the Armed Services and the CAA to determine the quality of materials or cause of failures. Analyses were also made of specimens from enemy airplanes. The principal causes of failure were fatigue fractures or corrosion or combinations of the two, improper manufacturing procedure, improper heat treatment, and undesirable features of design. Recommendations calculated to eliminate defects in material and design were usually made, except when the failures were due to overloading and were not predicated upon defects.

**Ordnance Materials**

A considerable amount of testing was done on ordnance material for the War Department. Fifteen tests were made of armor piercing shots and high explosive shells, ranging from 20-mm to 155-mm projectiles. Manufacturing difficulties encountered were failures of the seam welds in the base plates of high-explosive shells, and fractures at the driving band grooves of AP shot. Preheating was recommended to relieve the former difficulty, and the elimination of a sharp angle in the groove by providing suitable fillets was recommended to minimize the occurrence of the latter. An apparent defect revealed by the magna-flux test was found to be caused by the stringers of sulfide inclusions which are common in this type of free-machining steel. Electrodeposited copper driving-bands, leaded copper for projectile bands, brass and copper parts of artillery ammunition, fuze parts, smoke shells, brass-coated steel shells, and Hadfield manganese-steel body-armor were examined for the quality of the materials or causes of failures. Trench knives and machetes were also examined for quality of material and suitability for their intended use.

**Engraving Plates**

The severe rationing of nickel, chromium, iron and tin during World War II posed a very serious problem for the Bureau of Engraving and Printing in the procurement of supplies of these materials required for the production of engraving plates for printing Federal currency, bonds and other securities. In general, these plates are built up by bonding to a sheet of open-hearth iron (0.1 in. thick) an electroformed composite sheet (0.1 in. thick) consisting of a layer each of iron, nickel and chromium. Bonding was secured with 50-50 tin-lead solder supplemented by spot welding the outer borders of the plate. The principal aim of the metallurgical studies conducted cooperatively with the Bureau of Printing and Engraving by H. K. Herschman was to promote conservation of these metals either by using suitable substitutes or by increasing the useful life of the plates.

In many cases, plates failed in the early stages of service by cracking, believed to be associated with their flexing action during the printing operations. Thus an improvement in the flexural (endurance) properties of the plates was considered as offering a possible approach to the elimination of this difficulty with resulting increased service life. Accordingly, studies of means for improving the fatigue (endurance) properties of the plate material were undertaken. The initial studies dealt with the influence on the flexural properties of heat treatment of the electro-formed sheet before and after soldering. A concurrent investigation of plastic adhesives as a substitute for solders also was undertaken. Since the early results of the latter of these two studies offered promise of greater and more immediate benefits, precedence was given this phase of the work.

The use of a plastic adhesive for bonding the components of plates proved beneficial in four ways as follows:

1. It served as an efficient replacement for the solder which contained strategically important tin.
2. The brittle iron-tin constituent formed at the junction of the iron and the tin solder, which contributed adversely to the endurance properties of the plates, was eliminated.

3. Spot-welding, which produced coarse crystalline structures in welded areas and thus served as danger centers for initiating fatigue failure, was eliminated. The elimination of this plate-processing step also served to speed production.

4. Considerably fewer failures by cracking have been encountered, and the indications are that appreciably longer plate life has resulted.

Scientific Standards

In addition to its research and development functions in the physical sciences, the Bureau has custody of the national standards of physical measurement in terms of which all working standards in research laboratories and industry are calibrated. The necessary research leading to improvement in such standards is continually maintained. These standards embrace not only material standards such as the standard meter and kilogram but fundamental physical constants as well. During the war demands for calibration services associated with the physical standards and for information relating to constants and properties of materials, were greater than ever before.

Spectrochemical Analysis

The objective of this project was to provide spectrographic standard metal samples for the use of other laboratories. Standard samples of known composition and in proper forms are essential to the application of spectrographic methods. With the advent of the war, spectrographic methods of analysis were generally adopted by the principal metal industries because of the advantage of speed in testing. Practically all of the aluminum and magnesium and a great part of the steel production during the war was controlled in quality by spectrographic analysis. The need for certified standards of composition became acute particularly in the steel industry.

To meet the demand for standards this Bureau in 1942, initiated a program on the preparation and certification of steels to be issued as NBS Spectrographic Standard Samples. With the cooperation of the Bethlehem Steel Company and the Ford Motor Company, steel rod specimens were prepared and, in March 1943, a set of 24 NBS standard steel rods was issued. This first set of standards provided for the spectrographic determination of manganese, silicon, copper, nickel, chromium, vanadium, and molybdenum in plain carbon and low alloy steels. The group of standards was later extended to a total of 40 samples, representing 20 different compositions, and including certified values for aluminum and tin concentrations. The steel standards were issued to more than 200 Army, Navy and industrial laboratories.

The development of spectrographic standards was extended to boron steels in 1944, at the request of the War Metallurgy Committee and with funds provided by the Office of Production Research and Development of the War Production Board. Boron steels became of importance to war production when NBS Metallurgists found that small quantities of boron added to steels improved the degree of deep-hardening. This property permitted the substitution of a few thousandths per cent of boron for larger quantities of scarcer and more costly elements such as manganese, chromium, and molybdenum.

The problem of the spectrographic determinations of boron in steel was investigated and suitable spectrographic methods were developed. These methods provided for the determination of boron in the concentration range 0.0001 to 0.02 percent. A set of 12 boron standards, covering the range 0.0006 to 0.02 percent was prepared with the cooperation of the Bethlehem Steel Company. In addition to the production of standards, boron was determined spectrographically in numerous steel samples for a metallurgical study of boron in armor plate and similar types of steel.

The spectrographic standards project was expanded in 1945, with an increase in personnel and with added space for laboratory facilities. The preparation of standards for tool steels, aluminum, and tin metals was in progress at the end of the war. These standards, of importance to war production, will be equally useful in peacetime applications of the relatively new tool of spectrographic analysis.

The general analytical work of the spectrochemical laboratory under B. F. Scribner involved the analysis of a wide variety of specimens of importance to the war effort. Analyses were made for many Government departments including the War Department, Navy...
Department, OSRD, the Board of Economic Warfare, Maritime Commission, U.S. Coast Guard, War Production Board, and the NACA. Spectrographic methods, which permit nondestructive testing or the analysis of minute amounts of samples, were found especially useful for the study of specimens of military importance. A partial list of samples tested includes parts of American and Japanese airplanes and radios, robot bomb butterfly valve, German sextants, land mines, mechanisms of heavy mines, *ersatz* metal coatings on European-made containers, buttons and similar plated materials, ceramic and metal parts of jet-propulsion engines, foreign military helmets, soldiers' mess-kits, machine-gun cartridge links, parts of heavy guns, tracer-bullet charges, and marine fusible boiler plugs and condenser tubing.

Personnel of the spectrochemical laboratory supplied information in many instances to other laboratories engaged in spectrographic analysis related to war production. The information largely involved the development of analytical methods, the choice of equipment and the availability of Spectrographic Standard Samples. B. F. Scribner served as a member of the Advisory Committee on Spectrographic Analysis to the War Metallurgy Committee, in 1943 and 1944. The advisory committee supervised research projects that were sponsored by the War Metallurgy Committee for the investigation of spectrographic problems in connection with war production.

**Standard Samples**

Approximately 100,000 NBS Standard Samples (fee value about $260,000) were distributed during the war period; this was about four times the prewar rate. These standards were used by the Army and Navy, and by industries engaged in the manufacture of war materials, such as steels, tanks, planes, munitions, and aviation fuels, to check methods of testing raw materials, to control manufacture and to test finished products.

At the close of the war period the Bureau had available about 300 standards of different materials comprising steels, irons, ferro-alloys, nonferrous alloys, ores, ceramics, high-purity chemicals and hydrocarbons, oils, paint pigments, and a number of standards of reference such as radon, gamma-ray, lamp and photometric standards. During the war period 65 standards were renewed and a considerable number of new standards were added to the list. Among the new ones were 71 pure hydrocarbons, 54 steels for spectrographic standards, 9 steels for chemical standards, 2 tin ores and 24 paint pigments.

Standard hydrocarbons were purified by high-efficiency, high-reflux-ratio distillation, supplemented by crystallization. Their purity was determined by freezing point measurements. The samples were sealed in vacuo in special glass ampoules. These hydrocarbons are used in the calibration of analytical apparatus and instruments, particularly infrared, ultraviolet, Raman and mass spectrometers and for the analysis of the hydrocarbon components of aviation fuels, synthetic rubber and related materials.

Spectrographic methods for the analysis of steels are rapid and are thus particularly suitable for control of operations in volume production of steel. These methods were comparatively new at the beginning of the war period and much needed standards were not available. The NBS therefore prepared a series of fifty-four standards covering the chief types of carbon and alloy steels produced during the war. These steels were prepared in rod-form, 7/16 inch and 1/2 inch in diameter under the direction of B. F. Scribner and C. H. Corliss, and were certified for manganese, silicon, copper, nickel, chromium, vanadium, molybdenum, aluminum, tin, and boron.

The enormous expansion of steel production during the war led to a critical situation in the supply of certain alloying elements. To conserve and obtain optimum use of steel-alloying metals, such as tungsten, molybdenum, chromium, and nickel, a number of new steels were developed by the steel industry. Nine standards of these new steels were prepared by the Bureau for use in checking analysts and methods of analysis. These comprised National Emergency nickel-chromium steels 8837 and 9465, a high-sulfur stainless steel, a molybdenum-tungsten steel,
a molybdenum-chromium steel, a cobalt-molybdenum-tungsten steel, a chromium-tungsten steel, a boron steel, and a tin-bearing steel. They were prepared under the supervision of H. A. Bright.

A standard of a Netherlands East Indies tin concentrate and of a Bolivian concentrate were prepared at the request of the Metals Reserve Corporation for use as standards in connection with the operation of the new smelter at Texas City, Texas, and for use in preparing suitable methods for the determination of tin in shipments of ores.

G. E. F. Lundell and H. B. Knowles represented the NBS on a War Metallurgy Committee, organized to study the wide discrepancies in the tin contents of ores reported by various laboratories engaged in the analysis of tin ores. Two reports of this committee, "Tin Smelting and Reclamation Group, on Methods of Analyzing Tin Ores and Concentrates," were made to the War Production Board.

Army and Navy agencies purchased large quantities of paint pigments during the war. Color and tinting strength are important properties as regards quality of paint pigments. To facilitate testing for compliance to specifications, standards were needed. E. F. Hickson of the NBS, with the help of the industry, prepared a set of 24 standards of various red, yellow, orange, and black pigments for color and tinting strength.

The NBS Length section under L. V. Judson measured surveyors steel tapes and invar base-line tapes in considerable numbers for the U. S. Army Engineers, the Hydrographic Office of the Navy, and other war agencies; also for use in laying out industrial buildings, air fields and ship yards. Linear scales were tested for firms making war instruments, such as Bendix Aviation Corporation; sector disks were checked for angle; and length-measuring instruments were certified for the War Production Board and for Lend Lease to insure accurate machine production.

Blood counts are made under the microscope with the aid of special chambers ruled into minute squares to facilitate counting. For many years the NBS has tested these chambers to determine whether the rulings were properly spaced, since any error would vitiate the blood count. This work increased greatly during the war to meet the needs of the Army and Navy hospitals and the Manhattan project.

At the request of the U. S. Army Engineers the NBS undertook the production of graduated circles of high precision for use in theodolites. Stainless steel circles with a diameter of 4 inches were designed for the Gurley type of Army theodolite and approximately 80 of these circles were graduated by B. L. Page on the Bureau's circular dividing engine. To exemplify the high precision attained in this work it may be said that every graduated circle supplied by the Bureau for use in these theodolites was correct throughout, within 2 seconds of arc. Tests made by such agencies as the U. S. Coast and Geodetic Survey and the U. S. Army Engineer Board of the circles when mounted in theodolites confirmed this accuracy.

The War Department also requested the Bureau to undertake the photographic reproduction of graduated circles from precise glass masters. In cooperation with Raymond Davis of the Photographic laboratory, precise master circles were ruled in wax on glass preparatory to etching and tests for accuracy were made subsequently from the photographic reproductions.

Standard Weights

Any laboratory work throughout the country which required precise weighing necessarily involved standards of mass based on values determined by the NBS Mass section under L. B. Macurdy. The values of many sets of laboratory weights were determined and sent to all parts of the country. Because of the various restrictions and priority ratings which accompanied these requests, it seems certain that practically all of these weights were used in the war effort.

Weights for new pressure-gage apparatus were regularly determined. Such apparatus was required in investigating the explosive force of various propellant charges, both for research work, and in routine tests of individual batches of powder to determine the weight per load for a particular batch.
The amount of the propellant charges and the weight of the projectiles were also based on standards of mass tested for various Ammunition Depots and Ordnance Plants. During the two years ending June 30, 1941, 10,009 weights were tested. During the four years ending June 30, 1945, 26,535 weights were tested.

Volumetric Glassware

The great increase in the activities of research and control laboratories and hospital clinics during the war led to a corresponding increase in the demand for certified volumetric glassware, such as burettes, measuring flasks and pipettes. Thousands of haemacytometer pipettes used to dilute blood specimens in making counts of blood corpuscles were tested for the Army, Navy, and public hospitals, and for the Manhattan project. Hydrometers, capacity measures and various types of special apparatus were certified in great number. In all, the NBS Volumetric section under E. L. Peffer inspected and tested about 32,000 items of graduated glassware during each of the war years. A project of special interest was the determination of the density and thermal expansion of styrene for use in the synthetic rubber program.

Gages

The NBS Gage section under D. R. Miller made precision measurements of the diameter of 14,000 screw thread measuring wires and rolls used by ordnance inspectors and others in the measurement of working gages. The dimensions of a large variety of gages and mechanical items, totaling 15,000 in number, were also measured. The gages and measuring instruments tested included screw thread gages, plain cylindrical and plain taper gages, spline gages, cartridge chamber gages, gages for portable panel bridges, squares, sine bars, vernier calipers, height gages, and micrometer calipers, most of which were used in munitions inspection. Parts of engines of several different types were measured to determine rate of wear, and a considerable number of aviation spark plugs were also measured. Typical items of war material which were measured included oxygen breather connections, gun adapters, rocket jets, pipe thread bushings for phosphor bombs, film magazines of aircraft cameras, range finder tubes, threads on Japanese bomb fuzes, shells, and cartridge cases. Numerous measurements of surface finish were made, particularly of roughness used by Ordnance inspectors.

Assistance was given in the development of specifications, at the request of the War Production Board, for micrometers, dial indicators, calipers, and other tool and gage maker's inspection equipment. These specifications were made available as War Emergency Trade standards. Assistance was also rendered in establishing product or gage tolerances for new Ordnance products under development.

Gage Blocks

In the mass production of interchangeable parts for all types of mechanisms, such as guns, munitions, aircraft, and automotive engines precision dimensional standards become an absolute necessity. Such standards most commonly consist of sets of precision gage blocks, which were made to tolerances of 0.000002 to 0.000008 inch per inch of length by at least 10 manufacturers in the United States. The calibration of such blocks is accomplished by means of optical interference methods within possible observational errors of 0.000002 to 0.000005 inch per inch.

During the four years ending August 1945, more than 78,000 gage blocks and gage block accessories, both English and metric, were calibrated for the several branches of the Armed Services, gage manufacturers, manufacturers of war materiel, the Procurement Division, Lend Lease (Treasury Department), and others. A considerable expansion of facilities and personnel was necessary for the accomplishment of this work. In order to provide definite criteria for the acceptance or rejection of gage blocks, the NBS formulated specifications relative to length, flatness, parallelism, surface finish, hardness, and stability, which were issued as Letter Circular LC 725. There has been steady improvement in the general quality of precision gage blocks made in this country.
and these specifications were a factor in advancing this improvement.

The NBS also cooperated in establishing facilities for checking gage blocks in the Gage laboratory of the Cleveland Ordnance District by the training of two operators, in the setting up of equipment, loan of some items, and consultation.

**Screw Threads**

The Bureau actively participated in the development of certain war standards for screw threads by committees organized under the procedure of the American Standards Association, such as the war standards of truncated Whitworth threads and Acme threads. This participation consisted in the writing of specifications for screw threads and thread gages, the determination of suitable tolerances, and the preparation of tables of dimensions and illustrations. Such standardization was extended under the auspices of the Combined Production and Resources Board to include participation by British and Canadian standardizing bodies, so that agreement was substantially attained on truncated Whitworth, Acme, stub Acme, and buttress threads during the war. This collaboration is being continued, and further important agreements on screw thread and other standards are anticipated which give promise of being mutually advantageous in post-war developments.

The availability of the National Bureau of Standards Handbook, "Screw Thread Standards for Federal Services," prepared under the auspices of the Interdepartmental Screw Thread Committee was an important factor in standardization during the war. Because of the rapid advancement in the development of screw thread standards, frequent revisions of this handbook were necessary. Just prior to our entrance in the war, the 1942 edition was prepared, and more than 60,000 copies were sold. Handbook H28 (1944), a further revision, was issued in February 1945 and is now in general use.

**Thermometers**

The war brought an increased demand for thermometers that had been tested by comparison with the national standards. During this period, 10,255 laboratory thermometers were tested in the NBS Thermometry Section under Miss J. Busse and 243 resistance thermometers and 229 thermocouples were calibrated. More than 215,000 clinical thermometers were also tested for the Veteran's Administration during the war.

In addition, the NBS assisted the Army in the problem of measuring skin temperature; prepared devices indicating humidities near 80°F, using hygroscopic salts and dyes, for experimental use by the Army in Alaska; assisted the Navy by supplying temperature-controlled apparatus for calibration of temperature-sensitive elements; conducted special tests on 7 platinum resistance thermometers for the Signal Corps; assisted the Maritime Commission in revising specifications for shipboard and utility thermometers; tested composition-coated paper and pellets for use as temperature indicators by the Army; designed and calibrated thermocouples for use in engine installation temperature surveys for the Naval Air station, Patuxent, Md.; tested thermo-switches for performance for the Navy, and determined the temperature coefficient 0° to 300°F of two coils for the Manhattan project.

**Materials and Tools**

Shortages of materials and tools were one of the major problems of the war. Thus the creation of the vast rubber program, discussed elsewhere, was necessary when sources in the Pacific were no longer available. War-time demands for such common commodities as gasoline and anti-freezes created critical shortages for vital civilian activities. Studies were made of gasoline substitutes and anti-freezes were tested and evaluated, and these were only a few of the hundreds of similar investigations made by the Bureau. Two major projects, of interest not only during the war but later as well, were concerned with the production of alumina from domestic clays and the development of small diamond dies. The former program was necessary because, as in the case of rubber, the United States has in the past been largely dependent on foreign sources of bauxite. In
the latter case, Europe was the only economical source of the special diamond dies.

**Small Diamond Dies**

While the larger wire dies of both diamond and carboloy have been produced domestically for a number of years, all the small diamond dies from .0004 inch to .002 inch in diameter were imported from Europe. When the war completely cut off this supply and at the same time enormously increased the requirements for fine wire for radio, radar and other instruments, the Diamond Die Division of the War Production Board took active steps to encourage and assist domestic plants in the production of these critical dies.

Notwithstanding this effort, the number and quality of the dies produced up to January 1943, were below requirement and the assistance of the NBS was requested by the War Metallurgy Committee. A die laboratory was established at the Bureau under C. G. Peters for the purpose of studying and testing existing die drilling and wire drawing machines and processes, and developing new methods and equipment with the object of reducing the production time and costs, and improving the quality of domestic dies. Many companies either loaned or rented various machines. A number of wire plants furnished quantities of tungsten and resistance wire to be used in life tests of dies. The various types of die-drilling and polishing machines were operated according to established procedures and the time required to perform each operation was recorded.

From experience gained in this laboratory and from data obtained from foreign reports, the time required to perform the operations necessary to produce a die of about 0.0007 to 0.0010 inch in diameter by methods formerly in use was close to that given in the table following. It soon became apparent that no appreciable reduction in drilling time could be accomplished through refinements of the methods in current use in the industry. While the above work was being done, experiments with electrical methods for drilling dies were carried on in the NBS laboratory. These proved so successful that the time required for drilling the bell and cone was reduced to only 4 hours. Methods and equipment previously employed by the industry were abandoned and thereafter dies were made by a combination of electrical and mechanical methods.

The time required for these operations averages about as follows (in hours): blank Preparation, 2; bell Drilling, 2; cone Drilling, 2; polishing, 4; total, 10. This time of 10 hours compares very favorably with the time of about 125 to 150 hours for mechanical methods required to produce a good diamond die of less than .001 inch size.

Several hundred dies were produced in the laboratory by these electrical methods. Some of these were as small as 0.0003 to 0.0005 inch diameter. The majority, however, lay in the size range 0.0006 to 0.0009 inch.

For testing diamonds, finished dies and fine wire, equipment available in the spectrographic and interferometry laboratories was employed. Strains and inclusions in diamonds were determined with the polarizing microscope. The orientation of the die and crystal axes was measured with the X-ray microscope. Dies with windows were first inspected with the binocular microscope and then a careful examination was made of the contour, finish, bearing and orifice under direct and cone illumination with a higher-powered microscope. For permanent record, photomicrographs were taken of the die contour and orifice.

In order to determine the relative merits of dies of various forms and finish of foreign and domestic make, more than 1,000 sample dies were obtained from all available sources. These were given the tests described above and reports were furnished to die producers and users. In most cases the wire plants kept and supplied production records

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<td>Total</td>
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and returned the dies to the laboratory for re-examination.

From these data it was concluded that the principal cause of early failure of dies was the complete lack of polish or finish in the secondary cone, bearing and back surface. This condition led to rapid wear and the formation of fractures at the orifice. Occasionally, flaws or cracks in the die stone or poor workmanship in casing the die caused failure.

To test the productivity of dies made by the electrical and mechanical methods, life tests were run using both hot and cold wire drawing machines. Some of these tests were performed in the laboratory and others by commercial wire plants.

Poundage records from the wire plants on a large number of domestic dies drilled mechanically, few of which were less than .001 inch size, showed production of from 1/2 to 4 pounds of wire during the first life, that is, before wear had increased the die diameter by .0001 inch. Similar results were obtained in the laboratory. In fact most of these dies required polishing at the wire plant before they would draw wire without frequent breakage.

Better production was obtained with the electrically drilled dies. In the laboratory, one train of fine dies graded from .00146 inch to .00097 inch drew more than 15 pounds of resistance wire before showing wear of 0.00006 inch. Each of three finishing dies furnished to one plant produced more than 1,000,000 meters of tungsten wire while wearing from .00087 inch to .00092 inch.

Diamond Powder

Investigations of commercial powders in general use for drilling dies and jewel bearings and for cutting gems and industrial tools showed the designations of diamond powder grades to be in a very chaotic state. Request for the cooperation of powder producers met with generous response. A large number of samples of diamond powder, including grain sizes from less than one micron to more than three hundred microns, were furnished. These powders were inspected under the microscope and photomicrographs were taken at 400 magnification. To determine the form of the grains of the fine powders, photographs were taken with the electron microscope at 6,000 magnification. Grain sizes were measured with the micrometer microscope. From these data and from grinding and polishing tests made on diamond dies and tools and on jewel-bearing materials, grade specifications were formulated.

The number assigned to each grade is the average grain size in microns. The range is the allowable variation in particle size in microns for a grade. Not more than 25 percent of the total number of particles below the minimum size and none larger than the maximum size of the range is permitted. The shape of the grain and the allowable amount of foreign matter are also specified.

From this work Commercial Standard CS123-45 of the National Bureau of Standards was formulated. This standard specification has been approved and accepted by the producers and users of diamond powder and now forms the basis for commercial sales.

Alumina from Clay

The aluminum industry in this country depends to a considerable extent upon bauxite shipped by water. Shortly after the United States declared war, the Axis' submarines seriously interfered with these shipments. Consequently, it became important to utilize domestic sources of alumina, of which clay is the most abundant. At a conference in the spring of 1942 between Under-Secretary of War Robert P. Patterson, Assistant Attorney General Francis M. Shea, General Brehon Somervell, Lyman J. Briggs, and James I. Hoffman, it was decided to construct and operate an pilot plant on the NBS grounds for the extraction of alumina from clay.

To produce metallic aluminum it is necessary to prepare purified alumina, which, in turn, is reduced electrolytically in a molten bath of cryolite. In the usual Bayer process, the bauxite from which the alumina is extracted should not contain more than a few percent of silica, and it is this requirement that demands the use of selected bauxite. Largely because of the limited domestic supplies of low-silica bauxite, about 70 percent of the needs of the United States aluminum
industry was being imported shortly before our entry into the war. Because of this, emergency investigations were undertaken at numerous laboratories to develop processes capable of using some of the domestic supplies of less pure bauxite, of clay, and of other alumina materials.

The various methods proposed for the recovery of alumina from clays and high-silica bauxites can, in general, be divided into two groups—the alkaline and the acid process. In both methods the problems involved consist, first, in obtaining a high percentage recovery of alumina and, second, in separating effectively the alumina from the other constituents in the alumina materials, especially silica and iron oxide. Both methods were investigated by the Bureau successfully.

One of the fundamental principles of many of the alkaline processes consists in the conversion of alumina in bauxite or clay to sodium aluminate, which is readily soluble in water. The iron is readily removed since it is rendered very insoluble in alkaline solutions. The silica is only partially removed. The problem is to get rid of the bulk of the remaining silica. Consequently, the investigation was directed along these lines. It was discovered that, when certain salts are present in sufficient concentration, the amounts of silica contained in the resulting sodium aluminate solutions are much less than with sodium hydroxide solution alone.

On September 15, 1942, these discoveries were presented to the Alumina Committee of the War Production Board at a meeting held at the NBS, and this committee urged that the investigation be continued. This was done, and soon almost the entire staff of the Lime and Gypsum section under L. S. Wells was engaged actively on this problem.

As the war continued it became increasingly evident that the submarine warfare was being brought under control and that with the increasing importations of low-silica bauxite from British and Dutch Guiana, the necessity for new processes was not as acute as it had been. Nevertheless, the investigation was continued to the completion of two new alkaline methods involving the principle of the desilication of aluminate solution by the formation of compounds of the sodalite type with the use of salt solutions. One of these methods is applicable only to bauxites, the other to both bauxites and clays.

In the first method a novel feature is the extraction of bauxites with a solution consisting of a mixture of sodium hydroxide and sodium chloride. When the salt is present in sufficient concentration, the amounts of silica contained in the resulting sodium aluminate solutions are much less than when extractions are made with sodium hydroxide solution alone. This reduction is caused by the precipitation of silica from solution as the very slightly soluble compound, sodalite (3Na₂O·3Al₂O₃ · 6SiO₂·2NaCl), rather than as the relatively soluble sodium aluminum silicate hydrate formed in the absence of salt. Other sodium salts, including the carbonate, nitrate, and bromide, give sodalite-type compounds with sodium aluminum silicate. The chloride and nitrate compounds are the most effective in reducing the silica content of sodium aluminate solutions.

Alumina and soda are recovered from the bauxite-extraction residues by a modified soda-lime-sinter method. Alumina is precipitated from the sodium aluminate solutions by carbon dioxide. In the combined process, overall recoveries in excess of 90 percent of the alumina in high-silica bauxites are obtained.

In the second method, which is applicable to both bauxites and clays, the aluminous material is sintered at about 1,300°C with sufficient limestone to convert its alumina to calcium aluminate and its silica to dicalcium silicate. The sinter is then annealed by cooling it slowly from 1,300°C to 1,200°C. The annealed sinter dusts to a very fine powder which requires no grinding. This material is extracted with a solution containing about 200 g of Na₂CO₃ and 150 g of NaCl per liter, and an extract containing 70 to 80 g of Al₂O₃ and 1 to 2 g of SiO₂ per liter is obtained. By boiling the extract with a seed charge of synthetic sodalite, its silica content is reduced to 0.1 percent of the alumina content or less.

Alumina suitable for the manufacture of aluminum by electrolytic reduction is precipitated by passing carbon dioxide into the desilicated solution. About 95 percent of
the alumina in the clay is recovered by this method. This extraction is higher than any which has been reported as obtained from clay by other alkaline processes and equal to, or somewhat higher than recoveries obtained by acid extractions. Losses of soda are small. An outstanding advantage of the process is that all steps can be conducted at atmospheric pressure, whereas many other alkaline methods for the extraction of alumina require autoclave desilication. In cyclic operation of each of the two processes, the spent solution from the alumina precipitation step is used in the treatment of a fresh batch of material.

At the same time work proceeded on the acid process under J. I. Hoffman. The first part of the work was done with Army funds. Lt. Col. Henry M. Huxley and, later, Capt. Robert Banks acted as liaison officer between the War Department and the NBS. Preliminary plans for the plant were started in May 1942, but, owing to extreme difficulty in obtaining delivery of equipment, actual construction could not be started until about January 1, 1943. On May 16, 1943, the plant was put in limited operation and 10 days later the first satisfactory alumina was produced. For the two years following, the plant was in almost continuous operation, with only occasional shut-downs for improvements and repairs.

The process consists in (1) roasting clay at about 700°C, (2) leaching the roasted product with dilute hydrochloric acid, (3) filtering to separate the insoluble siliceous matter from the solution containing the aluminum and soluble impurities such as iron and alkali salts, (4) concentrating the solution, (5) precipitating the aluminum as the hydrated chloride from the concentrated solution by addition of hydrochloric acid gas, (6) removing the crystals of hydrated aluminum chloride by centrifuging in a rubber-coated centrifuge, (7) washing the crystals to remove adhering impurities, (8) calcining the hydrated chloride to obtain alumina and to expel combined hydrochloric acid which is used in the next cycle, and (9) recovering hydrochloric acid from the waste products at the end of the process.

The alumina obtained in this pilot plant has an average purity of about 99.6 percent, and significant impurities being 0.25 percent of chlorine, 0.08 percent of iron, and 0.06 percent of silicon. This compares favorably with alumina produced from high-grade bauxite ores. For some uses the alumina possesses exceptional properties, for example as a polishing material for metallographic specimens and as the raw component of certain heat-resisting enamels.

Alumina made by this process is more costly than the regular commercial product. However, reduction in cost of hydrochloric acid in large-scale operation, and improvement in operation of the plant should materially reduce the costs and render the process practical if ever a shortage of bauxite ore again threatens the industry.

Production of Elemental Sulfur From Pyrite

If pyrite (FeS₂) is heated in absence of air, the following reaction takes place:

\[ \text{FeS}_2 + \text{Heat} = \text{FeS} + \text{S}. \]

If the resulting FeS is treated with concentrated sulfuric acid, then:

\[ 3\text{FeS} + 4\text{H}_2\text{SO}_4 = 3\text{FeSO}_4 + 4\text{H}_2\text{O} + 4\text{S}. \]

Thus elemental sulfur can be produced from pyrite in two stages.

Because of the difficulties of transporting sulfur from the Gulf to the northern States and Canada, the utilization of Canadian pyrite to produce elemental sulfur became attractive. A Herreshoff muffle-fired furnace with continuous feeding equipment and exclusion of air seemed to be the logical way to determine whether reaction (1) could be made to yield sulfur on a commercial scale. Since there are very few experimental furnaces of this type, it was agreed that in cooperation with the Nichols Engineering and Research Corporation the reaction (1) should be put through the pilot-plant stage by using the experimental Herreshoff furnace in the Bureau's alumina pilot plant, originally furnished by Nichols for converting hydrated
aluminum chloride to aluminum oxide. This was done at intervals when the furnace was not needed for calcination of aluminum chloride, and was done with personnel furnished largely by Nichols. In all, 10 tons of pyrite were put through the furnace.

Analyses of the gases emanating from the hearths indicated that elemental sulfur was formed, and when a cooling system was installed, elemental sulfur was condensed, showing that the first step of the process is feasible. No plant has been built on the basis of this pilot-plant work because the high requirement for concentrated sulfuric acid in the second step (represented by equation 2) is said to render the process uneconomical.

Mica Films

Muscovite mica was a strategic material of great importance from the beginning of the war for the following reasons: (1) large quantities were necessary for certain ordnance and communication devices; (2) the domestic supply was limited and undeveloped; (3) the main source of supply in India was in danger of being cut off. The development of a domestic industry posed many problems, largely because previous production had depended mainly on tedious hand processes and cheap labor. The most tedious operation, and the one requiring the most skill, is the production of films 0.0003 to 0.003 inch in thickness for use in electrical capacitors and for insulation in airplane spark plugs.

At least 20 patents have been granted on mica splitting devices, but none of them has proved satisfactory for producing capacitor films. A project for developing a method of splitting mica was started by the National Research Council in 1942 and discontinued in 1944 without success. Several inventors have been working independently on this problem, and one has recently devised a machine which is reported to split about as fast as one hand splitter.

A project was started at the NBS in 1942 under D. W. Kessler to study the possibilities of rapid splitting by physical or chemical treatments applied to block mica. Many treatments were tried without success, and it was concluded that the only process that offered any possibilities was a mechanical device. Efforts were then made to develop a machine to remove films faster than can be done by hand splitters. Three distinct operations are necessary: (1) To start a split in the right cleavage plane to give the required film thickness; (2) to separate the film completely from the block; (3) to remove the stripped film from the machine and deposit it in a receptacle.

The first machine devised split mica blocks to the size desired at the rate of about thirty splits per minute, about equal to that of two hand splitters. The machine was faulty in that it was idle during the time the mica blocks were placed in position for splitting, and the device for removing the split films caused too much bending and distortion.

The second machine, designed to overcome the faults of the first, consisted of a metal disk mounted on a vertical shaft with six vacuum chucks equally spaced around the periphery. The suction areas on the chucks were made of various sizes and shapes to adapt them to the variations in mica blocks. The starter gage consisted of two small rollers mounted at the end of a bar which oscillated back and forth in a rectangular tube that was hinged at one end. The free end of this tube (the one nearest the chuck) was wedge-shaped and had a sharp steel point for starting the splits. In the starting position the gage rollers rested on the mica block with the starter point adjusted to the proper level for thickness. A carriage in moving toward the gage, pushed the chuck forward in its slide-ways a sufficient amount to make the point enter the mica and raise a film slightly. As soon as the starter point entered, the gage rollers moved back into the tube, leaving the film free to be stripped. Stripping was done by two thin wedges mounted on the carriage. The wedges passed under the started film, which was stripped loose with only slight bending. When the film was entirely separated from the block, it was picked up by a suction belt and carried away. With this machine the splitting is almost continuous since the operator mounts a mica block on one chuck while another block is being split. Shifting a loaded
chuck under the splitter requires about one second. A rate of 60 films a minute has been obtained with this device, and this rate could probably be doubled with the development of skill in operation. The rate is limited mainly by loading and shifting the chucks, but defective mica blocks often give trouble.

**Mica for Spark Plugs**

Numerous failures of aviation spark plugs insulated with mica led the Navy Department to request that the NBS try to determine the cause of these failures. Under war conditions mica was being obtained from new sources and the necessity of studying the physical properties of this new material was obvious. In fact the term mica is used broadly to include a large group of materials that can be split up into very thin sheets. Micas from various regions differ chemically, the aluminum in muscovite being partially replaced by magnesium, lithium, titanium, or iron to form other micas with accompanying changes in physical properties.

As a first step, a study was made of the thermal expansion of micas from various domestic and foreign sources. It was found that the coefficient of expansion of most of the phlogopite and biotite micas was extraordinarily high, many times that of any other known, solid material. On the other hand, the coefficient of expansion of muscovite, riplidolite, and zinnwaldite micas is relatively low. The elimination of the micas with abnormally high coefficients of expansion reduced the spark plug failures.

Laue X-ray diffraction patterns obtained between 200° and 800°C indicated that certain micas form a macromosaic structure when heated above 200°C which incompletely reverts to the initial condition when cooled below 200°C. This nearly reversible change in the physical structure could be correlated with breaks in the thermal expansion and contraction curves.

The power factor of the samples of phlogopite mica examined was found to be considerably larger than that of muscovite mica. Heating the samples to 600°C and then cooling produced a considerable increase in the power factor of phlogopite mica but only a small change in muscovite mica.

The enormous thermal expansion of phlogopite mica, resulting in disruptive forces when confined and its high power factor clearly showed its unsuitability for use in aviation spark plugs. On the other hand, the high thermal expansion of phlogopite micas may find useful applications in thermostatic devices.

**Conservation of Critical Materials**

Because its peacetime experience touched on the uses of many materials which were considered "critical" during wartime, the NBS was able to serve the War Production Board, its predecessor the Office of Production Management, and other agencies by showing how conservation measures could be effected. For example, military demands for nickel and copper made necessary the drastic curtailment of the normal annual consumption of 120-thousand pounds of nickel and 4 million pounds of copper in the manufacture of printing plates. Research conducted at the NBS showed that a large part of this copper and nickel can be replaced by iron deposited from suitable plating baths. These methods were used successfully by the Government Printing Office, the Capitol City Printing Plate Company of Des Moines, Iowa, and in a modified form by the Royal Electrotype Company of Philadelphia. In certain applications printing plates thus made were superior to those previously used.

Before these methods were extensively applied, the industry was permitted to use 60 percent of its normal consumption of copper, provided the metal was salvaged from used plates and scrap. Consequently the use of iron plating in the printing industry did not become widespread, but it was demonstrated to be practicable.

Many of the materials used in the manufacture of paints were on the "critical" or "strategic" list. Even before the outbreak of war, technical releases for the Office of Production Management had been prepared on substitutes which might be used for aluminum paint. The NBS demonstrated to the military agencies that the scarce pigment chrome yellow could be replaced to a large extent by yellow ochre in olive drab paint, camouflage paints, and shell coatings.
A good illustration of rising demands and falling supplies occasioned by war was supplied by the linseed oil industry. In 1942, about 79 million gallons of linseed oil were consumed in the United States. During 1941, this had risen to 109 million gallons, of which more than one-third was made from imported flaxseed. By 1942, practically no flaxseed could be imported. At the same time new demands had arisen for linseed oil, in part to meet the needs of our Allies and in part to replace imported oils, such as tung and perilla. For the year 1943, the War Production Board restricted the amount of linseed oil to be used in the paint industry for other than military purposes to 70 percent of the average for 1940 and 1941.

Early in 1943, the Bureau's letter circular on "Conservation of Linseed Oil in Paints," by E. F. Hickson, was issued to show both the paint manufacturer and the painter how to get around this difficult situation. An important recommendation was that the use of suitable amounts of a processed linseed oil, known as "bodied" oil, with appropriate changes in the general formulation of the paint, would allow a saving of one-fourth to one-third of the raw oil.

It is worth noting that the processed oil which came into much more general use because of this exigency is now considered to be more desirable in many ways than the raw oil. As in many other instances, the emergency created by war led to technologic advances.

An unspectacular example of many minor problems was the study of the extent to which wax could be substituted for stearic acid (a critical item) in producing candles satisfactory for Army use in the field.

**Iridium Salvage**

Platinum metals play an important part in modern warfare; they are essential in the production of sulfuric and nitric acids, in the construction of contact points for magnetos of aviation engines, in radar equipment, in fuse wire, in spinnersets, in plating search-light reflectors, and in various vital chemical industries and laboratories.

One member of the platinum family, the metal iridium, is more highly prized than the others because when added to platinum it forms hard alloys which are useful commercially. It was this property that made possible the setting of precious stones in iridio-platinum alloys and the development of iridium jewelry. These same alloys are also of use in wartime equipment.

The main sources of iridium lie outside the United States. Until the recent recovery of platinum metals in the Goodnews Bay district of Alaska, this country produced only an infinitesimal amount of iridium. To secure every available ounce of this critical metal for the prosecution of the war, the War Production Board restricted the manufacture of iridio-platinum jewelry and arranged a program for its salvage. It was estimated that between 400 and 700 troy ounces of iridium were contained in iridium-bearing materials in the hands of approximately 250 manufacturing jewelers. Arrangements to purchase the iridium-bearing material were made by the Metals Reserve Company, a subsidiary of the Reconstruction Finance Corporation. Baker and Company acted as purchasing agent for Metals Reserve and also as refiners of the iridium. The NBS Platinum Metals section under E. Wichers acted as official weigher and assayer.

In that portion of the program in which the NBS participated, 2,325 troy ounces of scrap were received. Of this, 194 ounces were found to be iridium, together with 2,065 ounces of the other platinum metals and gold. The iridium thus accounted for was not all of that salvaged by the program as a whole, because a considerable amount of unused plate was returned directly to the refiners without assay.

The iridio-platinum material weighed and assayed by the NBS consisted partly of unused plate, but mostly of scrap in the form of unfinished or old jewelry, clippings, filings, and buttons. In all, 125 lots of material were received for assay. Each lot had to be evaluated in terms of percentage of iridium, percentage of platinum, rhodium, palladium, ruthenium, osmium, and gold taken together as "precious metals," and the percentage of palladium if this constituent exceeded 1 percent. Because of the varied nature of the material received, sampling...
constituted one of the major problems. It was also necessary to develop methods of analysis specially adapted to the material.

Commodity Standards

Simplification

Simplification is the elimination of avoidable waste, through reduction in variety of types, sizes, etc., of specific manufactured articles produced primarily for stock purposes. Beginning with the defense program, NBS representatives participated in a great many of the early meetings of the National Defense Advisory Commission with industry groups, including the conference that became the model for future meetings of Industry Advisory Committees. These committees served as a liaison between industry and the Federal Government, and the Chief of the Division of Simplified Practice, E. W. Ely, secured the approval of General Counsel John Lord O’Brian of a plan of collaboration enabling the Division to work intimately with Industry Advisory Committees in matters pertaining to simplification. The Office of Price Administration and other war agencies also benefited from the work of the Division of Simplified Practice. A number of the existing Simplified Practice Recommendations were incorporated and identified in regulations issued by the OPA. In a good many instances the Division developed all of the basic data used in mandatory orders, and then assisted the Appeals branch of WPB in administering and revising them. Some of these orders are listed below, together with a valuation of each one, by WPB.

Cast Iron Tubular Radiators. L-order No. 42-I limited sizes and weights for 3, 4, 5 and 6-tube types. Savings: 23,000,000 pounds of cast iron, based on known requirements from March 1942 to March 1943.

Concrete Reinforcement Steel. L-order No. 211-I established permissible sizes of steel reinforcing bars and spirals. This increased production through more efficient use of existing facilities, and reduced mill and consumer-inventories.

Builders’ Finishing Hardware, Cabinet Locks, and Padlocks. L-order No. 236-I reduced number of items from approximately 27,000 to 3,600, (62 percent).

Dental Equipment and Supplies. L-order No. 139-I reduced the number of sizes of dental excavating burrs from 76 to 84, (66 percent), permitting manufacturers to concentrate on production of the few essential types, and to meet the increased needs of the armed forces.

Forged Axes, Adzes, Hammers and Hatchets. L-order No. 157-II reduced axes from 362 items to 147, (61 percent); hatchets, from 86 to 36, (58 percent); broad axes, from 12 to 5, (60 percent); adzes, from 11 to 9, (18 percent); and hammers, from 180 to 113, (37 percent). Conserved vital alloy steels.

Grey Cast Iron, Malleable Iron, and Brass and Bronze Pipe Fittings. L-order No. 42-II eliminated 65 percent of all types and sizes; conserved the use of various metals and increased production.

Hand Forks, Hand Hooks, Hand Rakes, Hand Eye Hoes, and Hand Cultivators. L-order No. 157-V specified definite types, sizes and weights allowed. Eliminated the use of all alloy steels and high-polished finishes, and allowed the substitution of other species of wood for ash handles, where buyer consented and species was plainly marked by name. Reduced variety and sizes from 815 to 128, (86 percent), with the resulting saving of between 600 and 1,600 tons of steel per annum.

Heavy Forged Hand Tools. L-order No. 157-IV reduced varieties from approximately 1,150 to 367, (69 percent). Delivery of tools to the armed services was speeded. Approximately 5 percent of the steel required (2,400 tons) was released for other uses.

Iron Body, Brass and Bronze Valves. L-order No. 42-I reduced the number of working-pressure ratings from 11 to 6, (64 percent). Later, the variety of the valves themselves were reduced from 4,079 to 2,504 (58 percent). This reduction cut down the use of brass and steel for manufacture. Material savings per year estimated at 650 tons of carbon steel; 1,900 tons of copper, which is approximately 9 percent of the amount used by the valve manufacturers; 4,340 tons of alloy steel, which is about 27 percent of that used in valve production.
Reduction in pressure-classes, of 33 percent and in production types, of 38 percent. Where possible, there was substitution of iron or steel for copper and copper alloys.

Manually Operated and Special Purpose Wood Saws. L-order No. 157-III reduced variety from approximately 800 to 210 (74 percent). Saved about 10 percent of steel (1,100 tons) required by industry.

Plumbing and Heating Tanks. L-order No. 199 reduced variety from 156 to 12 for range boilers, (92 percent). For expansion tanks, from 13 to 5, (61 percent). All double extra-heavy and riveted and welded range-boilers were eliminated, also metal tank-stands. It was mandatory to use standard steel sheets of 60 inch width, without shearing, or cutting-waste. Estimated savings: 10,000 tons of sheet steel and 2,825 tons of cast steel and iron.

Refrigeration Valves, Fittings, Accessories and Other Parts. L-order No. 128-IV reduced the number of types and sizes by 60 percent, to increase the production by approximately 15 percent, thereby releasing productive facilities for war work.

Shovels, Spades, Scoops and Telegraph Spoons. L-order No. 157-I reduced inventory requirements; made possible more orderly purchasing policies, thereby facilitating rolling mill schedules; released forging presses and other productive facilities to the manufacture of war materials; increased industry’s capacity for heat treating armor plates.

Welded Chain. L-order No. 302 fixed the types and sizes of chains and chain assemblies furnished for standard use, Sizes were reduced from 1844 to 346 (77 percent). Types were reduced from 138 to 66 (53 percent). This reduction in variety increased productive capacity by 10 to 15 percent and thereby decreased the 9 month’s backlog on the essential items by 13 to 20 percent within one year.

Wrenches, (L-order No. 216-II) and Pliers and Nippers, (L-order No. 218-III) reduced varieties to one style and one grade per manufacturer. Permitted sizes could be made in only one set of dimensions. Only special types of finish were allowed. Unnecessary polishing was prohibited. These orders increased production to meet civilian and military demands by 10 to 15 percent.

**Commercial Standards**

Commercial standards may be defined as voluntary recorded standards of the trade, developed through concerted action of producers, distributors, testing laboratories, and consumers. They cover terminology, types, classifications, grades, sizes, and use characteristics of manufactured products, as a basis for clear understanding between buyer and seller; describe standards methods of test, rating, certification and labeling, and provide uniform bases for fair competition. They are made effective by means of voluntary guarantees on invoices and labels, or by grade marks on the goods themselves.

During the war years the Division of Trade Standards under I. J. Fairchild cooperated with many industries in the establishment of commercial standards at the request of war agencies, and in some instances at the request of industries concerned, on subjects pertaining to conservation of materials.

Typical of the commercial standards developed during the war were the following: In cooperation with the War Production Board and various trade groups, commercial standards were established for several types of heating equipment, to provide satisfactory heating installations for war housing, and to conserve strategic metals and fuels.

Porcelain-enamed steel utensils, CS100-44, was established at the request of the Enameled Utensils Manufacturers Council, to provide satisfactory products to conserve aluminum, stainless steel, copper and other critical materials. The standard included performance requirements and methods of test to insure satisfactory durability of enamelled utensils for cooking, household food storage, and hospital use.

Hospital sheeting for mattress protection, CS114-43, was established at the request of the American Hospital Association to provide a serviceable substitute for the conventional rubber sheeting.

At the request of war agencies, several commercial standards were established for the sizing of apparel. In some instances
preliminary drafts and reports of broad surveys to determine trade reaction were used by the War Production Board and the Office of Price Administration as a basis for limitation and price orders, without waiting for official establishment of the standards. The personnel of the Division also cooperated with the Armed Forces in the sizing of WAVE, WAC, and Nurses' uniforms.

Douglas Fir Plywood, CS45-45 (sixth edition), was revised in cooperation with the War Production Board and the Douglas Fir Plywood Association. It was estimated that the revision provided additional production of about 20 million square feet per month over previous capacities. Plywood was used extensively in many war activities, such as the construction of barracks, concrete forms, boats, pontoons, etc. The supply was further extended by the establishment of Commercial Standards for Western Hemlock Plywood, CS122-45, Hardwood and Eastern Red Cedar Plywood, CS55-42 (a revision), and Homogeneous Fiber Wallboard, CS112-43.

Screw Threads and Tap Drill Sizes, CS24-43, was revised on recommendation of the Interdepartmental Screw Thread Committee. The Standard provides a convenient basis for specifying type, character and fit of threaded items used in guns, planes, ships, tanks and a wide variety of war material.

Mineral wool; loose, granulated or felted form, in low-temperature installations, CS105-43, was established at the request of the Industrial Mineral Wool Institute, to provide satisfactory replacement for cork and other critical insulating materials. A commercial standard was also established for mineral wool, blankets, blocks, insulating cement and pipe insulation for heated industrial equipment, CS117-44; and other insulating materials such as structural fiber insulating board, CS42-43 (a revision of a previously established standard).

At the instance of the War Production Boards and in cooperation with the trade, a number of drafts of commercial standards in the precision tool field were developed as a basis for expeditious and fair procurement by foreign purchasers as well as for government purchase from the greatly expanded number of producers of precision tool equipment. The standards established during the war period are: Dial Indicators (For Linear Measurements), Commercial Standards (Emergency), CS(E) 119-46; Master Disks, Commercial Standard (Emergency), CS(E) 124-45. Other drafts became the basis for the Federal specification for Calipers and Depth-Gages; Micrometer, GGG-C-104, and for Calipers; Jointed (lock, spring and firm) and Slide, GGG-C-8. In order to provide their attendant benefits in peacetime trade, industry is continuing the cooperative work on drafts of commercial standards for additional precision items such as sine bars, surface plates, toolmakers knees, angle irons and parallels.

Codes and Specifications

Air Raid Protection

On January 12, 1942, the President addressed a letter to the Administrator of the Federal Works Agency requesting that plans be developed to safeguard public buildings (except those under the jurisdiction of the Army and Navy) and the contents of such buildings from overt acts of aggression. As a result an Interdepartmental Advisory Committee on Protection was appointed by the Commissioner of Public Buildings to prepare suggested protective measures. This committee drew up the Air Raid Protection Code for Federal Buildings and Their Contents which was duly approved by the Administrator of the Federal Works Agency and was the basis for protective measures undertaken by the Public Buildings Administration throughout the country. The Congress appropriated the sum of $12,000,000 for this purpose. The Office of Civilian Defense ordered 100,000 copies of the publication for distribution so that the protection measures suggested could be utilized in other than Federal buildings. J. A. Dickinson, V. B. Phelan and G. N. Thompson represented the Department of Commerce on the Interdepartmental Committee, and the last-named served as chairman of the committee.

Plumbing

In November, 1940, the Bureau published the BMS66 Plumbing Manual, which had been prepared by a subcommittee of the Central
Housing Committee on Research, Design and Construction. The publication contained suggested requirements for design and installation of plumbing in Federal buildings. With the coming of war in the following year, the shortage of critical materials became a matter of deep concern. This problem was vigorously attacked by the War Production Board, which issued its Emergency Plumbing Standards, based on the NBS Plumbing Manual. Use of the standards resulted in substantial savings in plumbing materials, particularly metals. Savings made were variously estimated from 174 to 284 pounds of cast iron and other metal per two-story single family house.

**Emergency Specifications**

The disturbed conditions of supply of raw materials during the war period, together with greatly increased consumption by the military agencies, necessitated modification of many commodity specifications. For example, shortages of glycerol, oils, fats, rosin, and metal containers made it necessary to change the specifications for many soaps and detergents. Twenty "Emergency" or "Emergency Alternate" specifications were prepared for such materials, and about 50 in the field of paints, varnishes, and lacquers.

Because of the scarcity of many metals, especially nickel, copper, and cadmium, it was necessary to revise existing specifications for the electroplated coatings on numerous products, such as tableware and kitchen utensils, plumbing fixtures, electrical conduit and fittings, surgical instruments, and hardware. Many of the methods of test used in the specifications were developed or improved at the Bureau.

The scarcity of copper and chromium also led to changes in specifications for the wood-preservative solutions which were extensively used in connection with the construction of Army camps. A large number of aqueous mixtures of sodium fluoride, sodium arsenate, boric acid, and borax were studied and revised specifications prepared. These specifications are merely representative of the many that were developed by the Bureau during the emergency.
15. Scientific Services and Consultation

The preceding chapters have already revealed the large amount of work performed by the NBS for the armed services and other government agencies. This was no chance happening, for the Bureau has always acted in this capacity for the Government, and it was decided as a matter of policy that during the war the NBS would concentrate its efforts on research, development and testing for other agencies of the Government directly prosecuting the war effort.

The unique combination of staff and facilities in all the physical sciences made possible the solution of many problems, some major and others apparently limited in scope, that were critical for one or another Federal agency. In addition, the NBS was consulted on a myriad of scientific problems. Thus, during the war a daily average of 125 representatives of other agencies or industries engaged on war contracts called on the Bureau for scientific assistance. Some of these problems were solved in conference; some were solved by capitalizing on past NBS work; some were solved because the Bureau was working in the same general field of activity, often directing the very project in its broader aspects; and some were solved by setting up the appropriate program of research or testing. A few examples of such activity will illustrate this phase of the NBS war effort.

X-Rays

In 1941, the X-ray section under L.S. Taylor was asked by the Surgeon General to undertake a comprehensive program of testing X-ray equipment for the Army and to cooperate in the development of specifications for such equipment. Accordingly, pilot tests on all X-ray equipment were carried out in the NBS X-ray laboratory to determine whether the equipment complied with Army specifications. The machines tested were of two kinds: a 100 kv, 200 ma unit, complete with table and accessories, and a corresponding 100 ma unit. A total of 19 such generators was tested.

The specifications covering these units had unfortunately been drawn hastily with no realistic understanding of either the minimum standards of performance acceptable to the medical service or the maximum standards that could be demanded of X-ray manufacturers distracted by difficulties of procurement. It was soon found that none of the manufacturers had made a serious attempt to comply with these specifications, which was in part owing to the fact that the specifications were unnecessarily severe—unreasonably so in times of war. Furthermore, the Army had in the past accepted equipment from most manufacturers on these same specifications on the basis of incomplete compliance tests.

The problem was to decide—under trying conditions and in all too short a time—on a reasonable specification of performance and to insist on it in every instance. No machine submitted was found wholly acceptable when first tested. All machines required modifications—several involving complete redesign of the high-voltage transformer and controls—before their acceptance was recommended by NBS under the modified specification. In the end all manufacturers submitted acceptable units. The fine cooperation of the engineers and specialists of the several companies involved, at a time when all were overburdened with responsibilities of a most pressing nature, was a major factor in expediting this project.

Throughout the war the Veterans Administration requested the assistance of the X-ray section in testing X-ray supplies and in designing safe X-ray installations. The volume of such demands has increased progressively; the general trend continues upward.

The Bureau's aid in developing specifications for medical supplies and equipment was requested by the Medical and Surgical Supplies Committee of the Federal Specifications Board, which is charged with developing specifications in this field for all branches of the Federal service. Specifications for such materials as protective lead rubber, protective aprons and protective gloves were critically examined by members
of the X-ray section and studies were carried out to check the specifications finally decided upon.

The present high state of development of industrial radiology may be attributed to the war, during which most of the potentialities of the method were explored. From the beginning the Bureau's assistance was requested by industry both in setting up techniques for industrial radiology and in safeguarding the health of personnel working with X-radiation. As examples of the types of problems on which was requested the following are cited:

Unless extreme precautions are taken when a large shell is filled with TNT, cavities or porosities will develop within the filling while it is solidifying. A filled shell containing large cavities might explode inside the gun barrel, owing to the sudden setback of the TNT in the shell. In an effort to develop proper filling techniques and to discard all improperly filled shells the Bureau of Ordnance asked for advice and assistance. Pilot tests made with the NBS 1400 kv X-ray generator indicated that such porosities were detectable under suitable conditions. As a result of these pilot tests and on our recommendation a number of 1000 and 2000 kv X-ray plants were set up for routine and automatic inspection of all such shells.

A similar problem arose in connection with the propellant powder sticks used in large rockets. Here again the difficulty was due to porosities and cracks in the propellant powder stick which for this particular application was cruciform in cross-section, approximately 2 inches in diameter and about 30 inches in length. Propellant sticks containing cracks are characterized by non-uniform burning which results in an erratic trajectory. Accordingly, various methods of detecting porosities in propellant sticks were investigated by the armed services and advice was sought at the NBS in connection with the radiological testing of such sticks.

It was apparent that if all propellant sticks required by the services were to be radiographed, a large fraction of the photographic film production of this country would need to be earmarked for this purpose. Attempts were therefore made to determine whether photoelectric methods of detection used in conjunction with X-ray fluoroscopy might serve the purpose, but it was found that the method did not always detect the presence of serious flaws. Accordingly, the Army decided that all propellant sticks should be radiographed and large installations were set up for carrying out this work.

Numerous radiographic inspections were carried out for other services, including the radiographic examination of component parts of the proximity fuze used on rotating projectiles. Such radiographs were made for a period of about one year at a maximum rate of approximately 500 radiographs per month. A study was also made of the fissures in the walls of a test chamber at the request of the Allegheny Ballistics Laboratory, OSRD. This chamber had been constructed with very heavy walls for studying the pressure and temperature characteristics of powder sticks. Before completion it was discovered that fissures were visible on the outer surface. A radiograph made with the Bureau's 1400 kv generator showed that the fissures were of a very superficial nature, being less than 1/2 of 1 percent of the total thickness of the chamber wall, and the apparatus was successfully completed.

Before the outbreak of the war, the Secret Service asked NBS assistance in setting up means of inspecting all parcels addressed to the President in order to detect any which might contain bombs. Improvised X-ray equipment had previously been used without adequate protection of the operating personnel. A ray-proof radiographic installation was designed by the X-ray section and a unit made in accordance with these specifications was procured, which was found to be safe. Packages addressed to the President have since been examined by the Secret Service by means of this machine.

The health hazards involved in the industrial applications of X-rays are similar in nature to those in medical radiology and the methods of control necessary to safeguard personnel are comparable. For the past 15 years the X-ray section has been a chief source and a clearing house for data on X-ray protection in this country. The recommendations in NBS Handbook H20 have been
generally accepted as the basis for X-ray protection in all medical applications. During the five years preceding the war the NBS received frequent inquiries from those pioneering in the application of X-rays to industry asking our help in designing safe industrial X-ray installations. Most of the plans for the larger X-ray installations were sent to the NBS for suggestions and approval, including those for the Ford Motor Company, General Motors, and the Glenn L. Martin Company. Such inquiries increased in number as conditions became more grave. During the war, the staff made X-ray surveys in Navy yards, hospitals, and factories. Aside from their immediately practical value such measurements served as useful checks on protection data obtained at the Bureau.

Laboratory studies of protective materials were continued throughout the war for X-rays generated by potentials up to 1400 kv and became the basis for protection recommendations contained in the ASA Z54 Safety Code. The need for such a standard became especially urgent when, as a result of the war, many workers who had had no previous X-ray experience began using the radiation routinely without an adequate knowledge of the danger involved or the precautions to be taken. Accordingly, a technical committee of 50 members with George Singer of the NBS staff as chairman was established under ASA procedure to formulate a Safety Standard. The effective work of this committee resulted in a comprehensive "Safety Code for the Industrial Use of X-rays, Z54-1, 1946."

Coinage

The military demands for copper, especially for use in cartridge brass, made it necessary in 1942, for the U. S. Mint Service to find a substitute for the 5,000 tons of copper annually used in the production of one-cent pieces. The only available cheap metal was steel, which had to be protected against corrosion. Corrosion tests, made at the Bureau of steel coins coated with zinc and other metals showed that, unlike copper coatings, a zinc coating protects the cut edges. Hence the coins could be stamped out of zinc-plated sheets. Laboratory abrasion tests showed that a steel coin plated with 0.0005 inch of zinc on each side would probably give at least a few years' service. When they were first issued the white color of these coins caused confusion with 10-cent pieces. Methods were then developed at the NBS for darkening the coins when made. Before such measures were completed, copper and scrap cartridge brass became available in sufficient quantities to permit the minting of copper coins. These new coins contained only 90 percent instead of the 95 percent of copper of the standard one-cent pieces.

The Office of Production Management in 1942 proposed that the 75 percent copper—25 percent nickel alloy used in the 5-cent coin be replaced by an alloy of about 80 percent copper—60 percent silver to conserve the strategic metals, copper and nickel. Additive agents to alter certain properties of this alloy to avoid rejection in coin-operated devices was necessary. Preparation and testing of 32 different alloys resulted in the recommendation of 50 percent copper—50 percent silver with the addition of either 10 percent of manganese or 8 percent of manganese and 2.5 percent of aluminum. Both alloys met the requirement; the latter was more tarnish-resistant. This work was done in close cooperation with the Bureau of the Mint, Treasury, and formed the basis for the Mint's production of the substitute 5-cent coin using a silver-copper-manganese alloy. Because of fluctuations in the price of silver, the alloy actually used was somewhat poor in silver and rich in copper, in comparison with the 50:50 ratio recommended.

An examination of coins to determine the procedure giving a surface most resistant to tarnish was requested by the Director of the Mint. The coin blanks (Netherlands 1/4 guilder blank and Philippine 10 centavo blank) presumably were used for preparation of invasion coins. Two compositions, 640 and 720 silver, were received from each of the three mints, Philadelphia, Denver, and San Francisco. Examination showed that the treatment given at the Philadelphia Mint resulted in the heaviest and most resistant coating, the Denver Mint treatment was poorest,
the San Francisco treatment intermediate. The 720 alloy gave a more satisfactory surface than did the 640 alloy.

Electroplating

The war intensified the service which the Bureau normally renders as a clearing house for information on plating problems for other Government agencies. These problems frequently involve tests of coatings or studies on processes and products. A few typical examples are as follows: (1) The resistance to abrasion and corrosion of various black finishes on optical equipment; (2) the testing for the Quartermaster Corps of plated plastic insignia and buttons; (3) for the same service, testing and specifications for gold coatings on insignia and buttons; (4) in cooperation with the Quartermaster Corps, Army ordnance and other agencies, the standardization of the salt spray test, which is included in many military specifications; (5) for the Army Map Service, the testing of chromate finishes used to protect zinc lithographic printing plates during storage, transportation and use in the tropics; (6) for the F. E. A., methods were studied for cheaply converting scrap cartridge brass into copper sulfate for use as a fungicide in the vineyards of Italy and France; (7) the testing of plated articles to conform to Federal Specifications, which is conducted by the NBS in normal times, was extended and considerably changed in nature because of new military demands and because substitute metals and coatings were being used. Samples of plated products that were tested included: Tableware, signal mirrors and life-saving equipment for the Maritime Commission; signalling equipment for the Coast Guard; fuse parts for Army ordnance; insignia and buttons for the Army Quartermaster; ration cans and airplane parts for the Navy Department.

Electroforming and Rhodium-Plating

The NBS was frequently consulted concerning the processes used in the plants operated by the Engineer Board for the protection of 60-inch searchlight mirrors by electroforming. In particular, extensive tests were made of the rhodium solutions used to plate the thin layer of rhodium which constituted the reflecting surface. In this connection, a minor research disclosed the nature of contaminants in the plating bath which decreased the reflectivity of the deposited rhodium. Following this, a method was devised for purifying the contaminated baths without resorting to the costly process of recovering and purifying the rhodium.

Cooperation with OPM and WPB

During 1941, the NBS was frequently called upon by the OPM for information and advice regarding plating problems such as the substitution of plated steel for metals or alloys normally used, or the substitution of one plated coating for another. The Bureau also assisted the engineers employed by these agencies in making surveys of the supplies and consumption of materials in the plating industry and of the probable needs of the War and Navy Departments for plated products. Laboratory studies were made on numerous specific problems such as: (1) Salvage of copper. The most effective method proposed for this, stripping in cyanide solutions and redeposition of the copper, was commercially developed. (2) Plating of steel sockets with brass or zinc as substitutes for brass lamp sockets. (3) The testing of various plated coatings for cups to be used in the collection of rubber latex in Brazil. Zinc plating was found the most satisfactory. (4) Development of lead plating as a possible substitute for tin and zinc coatings. Tests on the resistance of lead coatings to atmospheric exposure are still in progress.

Motor Vehicles

Early in the war, a critical shortage of the standard anti-freeze compounds, ethylene glycol and ethyl alcohol, developed. In consequence a number of substitute automotive anti-freeze compounds appeared on the market. These compounds were chiefly of one of two classes, salt base or petroleum base. The former class were generally compounds of calcium chloride. Experience many years ago had shown that it was difficult, if not
impossible, to inhibit corrosion by calcium chloride anti-freeze compounds in automotive service. At the request of Government and industrial committees concerned with transportation the NBS under C.S. Bruce made an extensive series of service tests on a widely distributed automotive anti-freeze compound containing calcium chloride and inhibitor. This test demonstrated the dangerous corrosion attendant upon the use of such compounds. Tests were also conducted on commercial anti-freeze compounds consisting of petroleum fractions. It was found that even the most highly purified of these compounds would attack the rubber then available for radiator hose. Most of the inner lining was rapidly disintegrated by the petroleum product. The residue from the hose, being carried into the radiator, was deposited in the finer passages and caused a rapid loss of heat transfer capacity through the radiator. In consequence of these tests the War Production Board issued Limitation Order Number 258 which prohibited the manufacture and sale of automotive anti-freeze compounds based upon inorganic salt or petroleum fractions.

At the request of the Army, performance tests were made on a number of gasoline-powered lift trucks. The tests included lifting power, stability, lifting speed, safety, speed on level ground both unloaded and with the rated load, strength of lifting forks, and the ability to cross small obstacles. The test data were assembled in a comprehensive report for the use of the Army in selecting the models most suitable for specific types of work.

A similar series of tests of electrically driven trucks was made for the Navy. These trucks were designed for use in ammunition dumps and the tests included, in addition to the items listed above, static conductivity tests of the tires.

At the request of the Ordnance Department of the Army, NBS observers were furnished to assist in tests of Army automotive equipment under high temperatures in the desert and also under arctic conditions in northwest Canada. Tests in the southern California desert demonstrated that most of the vehicles would not continue to operate on the gasoline used by the Army. Necessary changes in fuel systems were made so that the equipment could operate satisfactorily on gasoline of 7.5 pounds per square inch Reid vapor pressure. Shortly after the African landing, attacks by submarines were making it necessary for tankers to so change their courses that the ultimate destination could not be established in advance. A tanker leaving the United States might arrive in Africa or in northern Russia. It was therefore necessary to develop an all-purpose gasoline which could be used in either location as desired, in order that equipment could be started at temperatures as low as \(-60^\circ\text{F}\) and yet operate satisfactorily in the desert. To do this the specification on Reid vapor pressure was changed to 5 pounds per square inch. The vapor-lock work in the desert therefore had to be repeated and the fuel systems of all Army vehicles changed so as to be able to operate on this gasoline without vapor lock at \(110^\circ\text{F}\).

Arctic tests were made during the winter of 1943, at Camp Shilo, Manitoba. Starting and operating tests were made on Ordnance vehicles at temperatures down to \(-40^\circ\text{F}\). This work showed that a single all-purpose fuel was feasible.

**Engines and Accessories**

In the latter part of 1943, a prototype landing-barge engine of 200 horsepower was delivered to the NBS for performance and development tests. While this engine failed by a small amount to complete the required 100 hours operation under the acceptance tests, its overall performance was good and a favorable report was made to the Army. Shortly thereafter a new engine of improved design was delivered and operated for about 1000 hours under various speed and load conditions. This engine was accepted for landing barge use on the basis of these tests.

In October 1943, a battery-operated torpedo motor being developed by the Navy was delivered to the Bureau for acceptance tests, which indicated that the motor would meet the requirements of the Navy. Torpedoes operated by electric motors, of which this was a prototype, subsequently were used with
outstanding success in the Pacific, as these torpedoes eliminated the wake which was left by torpedoes propelled by compressed air.

Toward the end of the war the NBS Automotive section was asked by the Office of the Quartermaster General to carry out an extensive series of tests on small air-cooled engines from about one to twenty horsepower. The purpose of this test program was to provide the Army with information on which an intelligent selection of engines could be made for specific purposes. The tests included determination of horsepower-speed relations on the dynamometer, and operation to failure under load. Simulated field service repairs were made on the engines after initial failure and the engines were then operated for several hundred hours more. Some starter-generator units and experimental engines were also tested.

During the war it was found that valves were sticking in Marine Corps trucks delivered on the West coast, whereas trucks off the same assembly line when delivered on the East coast, and driven to the point of destination, showed no such problem. A longer period of run-in at the factory was recommended in the case of the trucks for delivery to the West coast. No other cause for the trouble was revealed. At about the same time the factory began using chromium-plated valves and the trouble ceased.

Considerable difficulty was experienced in the operation of locomotive Diesel engines in the early phases of the European campaign. These difficulties arose chiefly from the cracking of cylinder heads and the breaking of cylinder sleeves. Examination revealed that the supporting member for the sleeves was too high. Replacement with an improved type of cylinder head relieved the difficulty.

At the request of the Office of the Quartermaster General, a number of so-called flame arrestors were tested. These devices are installed on the exhaust pipes of motor vehicles and are intended to prevent passage of flame when the engines backfire. Tests of a variety of such devices indicated that the flame was sometimes retarded or stopped, but that under high-speed operation each device failed to prevent the passage of flame. After considerable developmental work with no improvement in the results it was concluded that the devices were of no value and their use was abandoned.

At the request of the Navy Department a rather extensive investigation was carried out to determine the explosion hazards involved in the filling and repair of net flotation buoys filled with polystyrene foam and used for the flotation of submarine nets. These buoys are filled by adding liquid butene to polystyrene powder in the buoy. Upon release of pressure the dissolved polystyrene is expanded, forming a cellular structure throughout the buoy. Various tests showed that under the prevailing conditions of filling no explosion hazard was present. When buoys have been damaged they are normally repaired by oxy-acetylene welding. It was found that when the shell of the buoy was penetrated by the flame of a welding torch no explosion resulted although the foam burned slowly. When the buoy was filled with the optimum mixture of butene and air, mild explosions occurred but none of these were of sufficient violence to endanger a person working near the buoy. It was concluded that these buoys could be filled and repaired without undue hazard.

**Heat Transfer Studies**

Some of the war work of the Heat Transfer section under R. S. Dill was the same in nature as that undertaken before the war but the types of material, devices and equipment investigated changed to those of interest to the Army, Navy or Maritime Commission. Insulating materials, air filters, heating and cooking stoves, furnaces, boilers, radiators, convectors, chimneys, etc., continued to be investigated, but the stoves received were intended for use in barracks, the insulating material was for use on shipboard or in Army refrigerating equipment and the convectors were marine types instead of apartment-house designs. In addition, research was undertaken on Army refrigerating
equipment, cooking equipment, airplane heaters, gasoline-water separators and breath heat-exchangers for arctic wear.

Refrigerating Equipment

Projects undertaken at the request of the Office of the Quartermaster General in the development of field cooking, heating and refrigerating devices led to the design and construction of 5 secondary-refrigerant calorimeters for the use of the section. Such calorimeters are used for testing refrigerating compressors and condensing units under standard conditions. They were practically in daily use during the last year and a half of the war. Choice of cooling equipment in Army refrigerated trucks, trailers, warehouses and portable field units was based on data obtained with these calorimeters.

Tests of complete refrigerators were made in airconditioned rooms arranged for the purpose. These included trailers, trucks, portable units and walk-in refrigerators. During such tests, data were obtained on the capacity of the refrigerating machine and on the efficacy of the insulation and vapor barriers. Most of the units were designed for food storage and transport, but some of the portable units were to be used for the transportation of blood serum and whole blood. In the development of a machine for a special purpose several samples were usually constructed by cooperating manufacturers and submitted to the NBS for trial. From these tests final designs were evolved in cooperation with the Quartermaster General's Office, the manufacturers, the Surgeon General's Office and other Army organizations.

Practically all machines that were received employed Freon 12 as a refrigerant. Experiments were made with equipment of the absorption type, using ammonia and water, but such equipment was not brought to a practical stage of development for Army use.

A number of thermal insulating materials, some newly developed, were tested for use in Army refrigerating equipment. Probably the most interesting were those made of plastic materials or artificial rubber, by a process which incorporates numerous air bubbles in the plastic or rubber before it sets. Pre-war insulators such as cork, cotton, and mineral wool were used in many Army refrigerators in preference to the newer materials. The Navy was a large user of a new type of glass wool with very fine fibers which has a comparatively low conductivity and weight.

Heating Equipment

The Army found that cooking stoves and ranges could not burn gasoline containing tetryethyl lead because the lead was deposited and soon clogged the gas ports. This trouble was also present in gasoline lanterns and some tent and barrack heating stoves. Practically all the gasoline supplied in the field contained the lead antiknock compound, and it was considered impractical to furnish a special fuel for cooking, lighting, or even for heating purposes.

Information on the problem was gathered and models were constructed for trial. Two general solutions were found. One was a filter which removed enough of the lead compound from the gasoline, ahead of the burner, so that a conventional stove would operate; the other was the Hartung burner, which is not seriously affected by the compound. In fact the latter burner was found to function with fuels ranging in properties from aviation gasoline to heavy fuel oil. It was applied to existing cavalry cooking stoves, tent heaters and field water heaters, and was used in improvising tent heaters from oil drums.

Heat losses from tents were investigated and the heaters used for warming airplane engines in the Arctic were tested for capacity and operating characteristics with a view to adapting them for heating hospital tents in the north. These heaters burn gasoline and consist of a burner, a heat transfer surface and a blower, driven by a small gasoline engine, to force the warmed air through canvas tubes into the tents.

Tests were also made on coal-burning stoves intended for barrack heating and the heating capacity of existing stoves was increased by enlarging and rearranging the heating surface.

"Canned" heat was marketed by several manufacturers at the beginning of the war
with no standardization of the container or of the fuel. A standard testing and rating method was developed to meet the satisfaction of the Army authorities. The chief interest was in the heating capacity available on per unit weight which the soldier must carry.

The Heat Transfer section assisted the Trade Standards Division of the Bureau in the development of standards covering cooking and heating equipment at the request of the housing agencies of the Government in an effort to conserve metal and other strategic materials. Several commercial standards resulted. Stoves and ranges made wholly or partly of ceramic materials were tested, but of these, only one cooking range was found satisfactory and it is doubtful if it is cheap enough to compete with other stoves in peacetime.

Chemical Investigations and Tests

In addition to the major projects described under separate headings, a great many minor assignments were undertaken by the staff of the Chemistry division. This was possible because of the experience acquired in the widely diversified peacetime work of the division. The assignments ranged all the way from analyses and tests closely related to those frequently made for Governmental agencies to investigations which required from a few days to many weeks of study by one or more specialists. Some five thousand samples of camouflage paint were tested in the paint section under E. F. Hickson for the Army Corps of Engineers. Many paints, both for camouflage and regular uses, were tested for the Navy and the Maritime Commission. Other examples of this kind were the examination of a variety of varnishes and related materials for the War and Navy Departments, the Maritime Commission, the War Production Board, and the Panama Canal; and of bituminous materials for various purposes, including the coating for the "Little Inch" pipe line.

Specialized knowledge in the field of roofing materials and roof construction made it possible to give expert advice to a branch of the Corps of Engineers charged with the maintenance of almost forty square miles of roofs on cantonments and similar buildings. Many of the roofs were defective because of the haste in construction and inadequate knowledge on the part of many contractors regarding roof construction. H. R. Snoke inspected the defective roofs and provided detailed instructions for their alteration and repair. The savings effected by this field service were estimated by the Corps of Engineers at $30,000,000.

Chemical microscopy was often employed by C. P. Saylor to determine the kind of materials in many types of captured enemy equipment such as range finders, coverings of airplane wings, protective coatings, films on airplane pistons designed to limit corrosion, field glasses and compasses. Chemical-microscopic studies also, in a number of instances, served to disclose the causes or mechanism of corrosion of vital parts of military equipment such as retractable landing gear, electrical connectors and priming caps. A striking example of this type of work was the study of the material which caused a stoppage of the fuel lines, during flight, in the plane used by the Under-Secretary of War. This material proved to be a corrosion product resulting from the reaction of an ingredient of the sealing and slushing compound used in the gas tank with the cadmium plating of a fuel strainer. The product does not form except when both gasoline and water are present in the fuel system and the plane is in only occasional use.

In another laboratory many organic materials were examined under W. H. Smith for the Quartermaster General. The following were typical: Solid fuels for ration kits, water-resistant and wind-resistant matches, hand warmers, mosquito repellents and compass liquids. Many of the samples represented captured enemy material. The information gained was used in experimental work, for the preparation of specifications, or to determine changes in the economic status of the enemy. For Naval Intelligence, liquids used in enemy ordnance were examined and their composition duplicated. Miscellaneous materials examined were de-icing compounds, ointments for camouflage, army duck which caused skin irritation, and lubricants for fittings for oxygen lines. Assistance was
given to the F. B. I., and to Army Intelligence on secret inks and other materials related to espionage. Work was also done on inks for impressions to be copied on microfilm, and on mildew-resistant typewriter ribbons for use in the tropics.

Several problems came within the province of the gas-chemistry laboratory under E. R. Weaver. At the request of the Bureau of Ships, following reported asphyxiation on board heavily-painted ships, a study was made and reported of the composition of gases produced by over-heated paint and the conditions under which explosive and asphyxiating atmospheres could be expected to form.

At the request of the Board of Economic Warfare, a substitute for kerosene in the lamps used in the tropics was sought among possible indigenous vegetable products. The best thing found was turpentine in alcohol solution.

Tests were made at various times of a considerable number of fuels and fuel-burning appliances. A small collapsible stove was designed for heating cups in the field. It had high efficiency, was almost entirely unaffected by wind, and produced no visible light. It was carried as a jacket on the cup and weighed only a few ounces. A noiseless gasoline-burning mantle lamp was also designed and a model constructed. Both of these developments were made too late to be put to use, however.

Nearly a thousand analyses of gaseous mixtures were made for agencies outside the Bureau and more than a hundred mixtures of gases were prepared for use as standards of known composition.

The electrical conductance of aqueous solutions often affords much information about related properties of the solutions, as well as their composition. Conductivity measurements by C. G. Halmberg were used in some of the problems of the Manhattan Project, in the development of the proximity fuze, and in determining the contamination of boiler-feed water by sea water in the Navy's ships.

The staff of the ferrous and nonferrous analytical laboratories under H. A. Bright made chemical analyses of many metallurgical materials for various military agencies. The materials included aluminum and magnesium aircraft alloys, compass alloys, jet-engine turbine blades, ship plates for the Maritime Commission, corrosion deposits in gasoline lines, engine sludges, special gasolines, sludges from aircraft hydraulic systems for the N.A.C.A. and captured ordnance steels.

In connection with the project on hardenability of steels, carried out for the War Metallurgy Committee, several hundred steels were analyzed for boron and nitrogen by K. D. Fleisher. The boron contents of the steels ranged from 0.0002 to 0.006 percent and required the development of new methods to obtain the required accuracy for determining both acid-soluble and acid-insoluble boron.

The laboratories working on detergents and miscellaneous materials under J. H. Smither were occupied with a variety of assignments. For the War Department, accelerated aging tests were made on water purification tablets to determine their stability under field conditions. Other studies were made on powdered soaps to determine the effectiveness of certain additives in reducing the probability of spontaneous combustion in storage, on ski waxes, and anti-chap materials to furnish data for specifications, on methods of test for flame-proofing mixtures and chlorinating agents, on captured German soaps and aviation engine coolants, on floor maintenance in Army hospitals and posts, and on specifications for detergents and detergent aids.

For the Navy, experimental work was done on the soldering and cleaning of electrical connectors from aircraft, to assist in establishing and eliminating the causes of corrosion of these parts. Studies were also made of the deposits in aviation engine cylinder heads; of the charges from chemical heating pads; of the condensates from a distilling unit designed for use on life boats and rafts; and of the quality of drinking water stored in aluminum containers to determine whether the containers had been properly cleaned after manufacture.

For other agencies this group studied corrosion products in boiler tubes, examined soaps in connection with regulations covering the addition of certain materials
designed to extend the supply of fats and oils, tested anti-freeze solutions, and determined the suitability of detergent-impregnated papers for use with North African water supplies. Hydraulic brake fluids were tested to determine their suitability for use in automobiles. Fuel additives claimed to improve the performance of gasoline were examined, likewise so-called motor conditioners and carbon removers. A large number of materials to be exported under Lend-Lease were tested to insure satisfactory quality. Soaps from Turkey, Brazil, and Guatemala were analyzed to determine their suitability for use by UNRRA. Various waxes and other materials were examined to see whether they could be substituted for materials on the critical list. Finally, a variety of materials was tested to help the Federal Trade Commission in preventing unscrupulous persons from taking advantage of wartime shortages to defraud the public.

During the war many instances occurred in which the measurement of acidity or alkalinity in organic media was important. The need for this had been anticipated at the NBS by a project begun in 1941 under S. F. Acree. In the course of the work more than 150 dyes were investigated, including 32 indicators specially synthesized for this purpose. A great variety of solvents was studied. Several of the synthesized indicators were found applicable to measurements of acidity or alkalinity in such substances as mineral and vegetable waxes, cellulose derivatives, lubricating greases, resins, transformer oils, and various kinds of turpentine. Spectrophotometric measurements of visible and ultraviolet spectra were used in determining impurities and in studying the quantitative relationships of the indicators with acids and bases of various strengths.

A by-product of the work was the application of selected indicator dyes to such purposes as testing aqueous extracts of concrete and reclaimed rubber, differentiation of spores in connection with the eradication of white pine blister rust, studies of sugars, analysis of glass batch ingredients, reactions in experimental dry batteries, and the testing of boiler waters in Army camps overseas.

**Fire Resistance**

In the early days of the war, black-out drills were carried out in Washington, and other measures were taken to protect the Capital as far as possible against bombing attacks. In this connection an experimental study under S. H. Ingberg was made of the protection needed to prevent the ignition of wood-roof or attic constructions by German magnesium incendiary bombs. Three reports were issued, giving more definite and detailed results than had previously been available, together with information on the penetration of roof construction by incendiary bombs.

Strength tests were made of wood-roof constructions covered with concrete mats as bomb protection, the concrete being bonded to the wood to form composite members and thus reduce the stresses on the wooden supporting members from the added weight. Burning tests using thermite bombs up to the 100-lb size were also made on various types of floor and roof constructions. The ignition temperature of magnesium and various incendiary mixtures was determined. Information was obtained on the burning temperature of magnesium, thermite and phosphorus for the information of the Chemical Warfare Service.

A memorandum was submitted to the tactical unit of the Army Air Forces on combined incendiary and explosive bombing. Beginning early in 1944, this method was used against targets such as the industrial areas of Germany where even buildings with wood interior construction had been made very resistive to incendiary bombing alone, and a high degree of organized defense against it had been achieved. Subsequent reports from the Twenty-first Army Group indicated that there was no defense against the destructiveness of 2-ton bombs mixed with thousands of incendiaries. Photographs after the last raid on Magdeburg showed 2000 separate fires.

At the request of the Navy, fire tests were made with Navy paints on steel and aluminum, and reports were submitted on the fire hazards and on the gaseous products of combustion. Before the war, the Navy apparently had not been much concerned with
the excessive thickness of coatings resulting from repeated repainting. Experience showed that the burning of these heavy coatings of paint contributed to the destruction of ships during the early part of the war and created undue apprehension as to the hazard of the usual thinner coatings. The reports were designed to be helpful in adopting a safe policy which provided for the necessary protection of the metal without requiring an undue amount of critical time and manpower to be expended in chipping off relatively thin coatings.

Considerable work was done for the Navy on the development of treatments for textiles for clothing of personnel exposed to fire and explosion hazards, and assistance was given laboratories and explosives plants in establishing a routine treatment. Tests were made of the fire hazard of textiles treated with DDT in flammable solvents for the Naval Medical Research Institute and the National Housing Agency. On request of the National Housing Agency methods were developed for treatment of mattresses to prevent ignition by people smoking in bed. A large volume of routine testing of fire-retardant-treated cotton duck was done for the military services and of blackout materials for the Office of Civilian Defense.
Appendix

Scientific and Technical Divisions and Sections

The organization of the National Bureau of Standards as presented below is the present organization. Some changes have been made since the war years.

Electricity and Optics

Resistance Measurements
Inductance and Capacitance
Electrical Instruments
Magnetic Measurements
Photometry and Colorimetry
Optical Instruments
Photographic Technology
Electrochemistry

Chemistry

Paint, Varnish, and Lacquer
Surface Chemistry
Organic Chemistry
Analytical Chemistry
Reagents and Platinum Metals
Electrodeposition
Gas Chemistry
Physical Chemistry
Thermochemistry and Hydrocarbons
Spectrochemistry
Uranium and Related Materials

Mechanics

Sound
Mechanical Instruments
Aerodynamics
Engineering Mechanics
Hydraulics

Organic and Fibrous Materials

Rubber
Textiles
Paper
Leather
Testing and Specifications
Organic Plastics

Metallurgy

Optical Metallurgy
Thermal Metallurgy
Mechanical Metallurgy
Chemical Metallurgy
Experimental Foundry
Underground Corrosion

Mineral Products

Porcelain and Pottery
Glass
Refractories
Mineral Products—Continued

Enameled Metals
Building Stone
Concreting Materials
Constitution and Microstructure
Chemistry of Mineral Products

Building Technology

Structural Engineering
Fire Protection
Heating and Air Conditioning
Exterior and Interior Coverings
Codes and Specifications

National Applied Mathematics Laboratories

Numerical Analysis
Computation Laboratory
Statistical Engineering
Machine Development

Commodity Standards

Metal and Ceramic Products
Textiles and Apparel
Mechanical Equipment

Commodity Standards—Continued

Packaging
Chemical Products

Electronics

Ordnance Tests and Evaluation
Ordnance Research
Ordnance Electronics
Ordnance Mechanics
Ordnance Engineering
Engineering Electronics
Guided Missiles
Guided Missile Electronics
Electron Tube Laboratory
Electronic Computers

Central Radio Propagation Laboratory

Basic Ionospheric Research
Basic Microwave Research
Regular Propagation Services
Frequency Utilization Research
Experimental Ionospheric Research
Field Operations
High Frequency Standards
Microwave Standards