WORLD WAR II RESEARCH (1941–45)

CHAPTER VII

"IN THE EVENT OF WAR"

The second worldwide war was foreshadowed in the Japanese invasion of Manchuria in 1931, Mussolini's invasion of Ethiopia in 1935, and Hitler's march into the Rhineland in 1936. Isolated and safeguarded by successive Neutrality Acts passed in 1935, 1936, and 1937, which barred the sale of arms or munitions to any warring nation, America watched the piecemeal fall of small nations, Austria and Czechoslovakia to Hitler, Albania to Mussolini. With the German attack on Poland in September 1939, Britain and France declared war against the dictators and World War II began. The first amendments to the Neutrality Acts were enacted.

By temperament strongly neutral and still in the grip of depression, the Nation had willed belief in Chamberlain's "peace in our time" until shaken by the occupation of Czechoslovakia in the spring of 1939. But certain of war and of America's inevitable involvement was the small band of foreign-born scientists, their spokesman Niels Bohr, who had recently arrived in this country. Shepherding atomic research here, Bohn at once urged restriction in all Allied countries of the publication of further data on the possibility of nuclear fission. Many individual scientists refrained, but control of publication in American scientific journals did not become effective until almost a year later, following Hitler's invasion of Denmark and Norway.

The National Bureau of Standards, convinced by the physicists on its Advisory Committee on Uranium of the certainty of a general war, began to put its affairs in order. On September 1, 1939, the day Germany marched into Poland, and one week before the President declared a state of limited national emergency, Dr. Briggs sent to the Department of Commerce a memorandum of the services the Bureau was prepared to render "in the event of war."

In the event of a European war, the Bureau was ready to test all materials to be purchased under the President's recent Strategic Materials

Act, and to increase the output of its optical glass from the current 9,000 pounds to 75,000 pounds per year. It was prepared to certify U.S. materials sent abroad, especially optical and electrical instruments, master gages, aircraft instruments, textiles, metals, and cement.

Should the United States become involved, the Bureau was prepared to solve technical problems of the military services submitted to it, as it had in the First World War. It would test supplies, particularly high precision instruments such as certain electrical and optical instruments, gages, screw thread standards, rubber, textiles, paper, leather, plastics, metals, and glass. It was also ready to assist in the development of new specifications for war materials.

Attached to the memorandum of readiness was a copy of "The War Work of the Bureau of Standards," covering the activities of the Bureau in 1917–18.[1]

Although the Bureau signified its readiness, the Nation was as unprepared for war as it had been two decades earlier. In 1939 the Army had 500 ancient tanks, 5,000 airplanes, 2 million old rifles, and scarcely enough cartridges for a normal year's training. Even 3 years later trainees were to qualify with the pistol for lack of rifles, and maneuver with simulated guns and tanks.[2] The Navy's newest battleship was 20 years old, and the British fleet was still the first defense of our shores. Across the country, more than 9 million people were unemployed, and industry, despite the production potential it had achieved through the application of science, standardization, and operating efficiency during the depression years, clung to its wait-and-see attitude.

As early as the spring of 1938 the President had promulgated the idea of "educational orders" to assist industry in tooling up for the production of certain war materials. Yet 2 years passed before the first order was actually issued.[3] Other orders, little publicized, followed. The President knew that the majority in the Nation was far from committed to the idea of war. The central issue of the campaign of 1940 appeared in the Democratic Party Platform: "The American people are determined that war, raging in

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[1] Memo, LJB for John M. Johnson, Assistant to Secretary of Commerce, Sept. 1, 1939 (NBS Box 429, AG).

[2] Reinhardt and Kintner, The Haphazard Years, pp. 165, 188.

[3] The order, promptly accepted by the steering gear division of General Motors, called for 500 .30 caliber Browning machine guns. It was not received until June 1940. In March 1941 the first machine gun ever made by an automobile company was completed. Donald M. Nelson, Arsenal of Democracy; the Story of American War Production (New York: Harcourt, Brace, 1946), pp. 225–226.

Europe, Asia, and Africa, shall not come to America. We will not participate in foreign wars. * * *"[4]

Even as fear rose with the collapse of France and apprehension over the spectacle of beleaguered Britain, the isolationist temper prevailed. Preparations for national defense moved slowly, consistent with plans to supply and support Britain, without upsetting the commitment to the electorate. In June 1940, without fanfare, the President approved the mobilization of science through the creation of the National Defense Research Committee. Over violent protests, Congress enacted the Selective Service Act on September 16, 1940, drafting 1.2 million men for a year of defensive training—an act whose extension just 6 months before Pearl Harbor was to pass by a single vote. The Office of Production Management, set up on December 20, 1940, offered to provide counsel, but little more, for the mobilization of industry.

In the spring of 1941 the President's Office of Price Administration established rationing, to control the rising cost of living. Volunteers manning 5,600 price and rationing boards began measuring out allowances of canned goods, coffee, sugar, meat, butter, cheese, shoes, tires, gasoline, and fuel oil. The nation's undeclared war, marked by Lend-Lease, the President's declaration in May 1941 of an unlimited national emergency, and the arming of our merchant ships, ended with Pearl Harbor.

The reluctance that delayed educational orders to industry for weapons production was reflected in a Bureau letter of February 1940. In reply to an inquiry from Military Intelligence, Dr. Briggs reported that the Bureau was conducting "very few projects * * * for the War Department."[5] In the decade before the war Congress had appropriated every dollar requested by the military for research and development, yet as war neared the Nation remained pathetically unprepared from the standpoint of new weapons. Taking the initiative at the instigation of a few key scientists, the Council of National Defense, with the approval of the President, set up NDRC on June 27,

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[4] Quoted in Edgar E. Robinson, The Roosevelt Leadership, 1933–1945 (Philadelphia: J. B. Lippincott, 1955), p. 257.

In his annual message in January 1940, Roosevelt requested almost $2 billion for national defense. In May he asked for a program of 50,000 planes a year, and with the fall of France imminent requested an additional $1.28 billion for accelerating the development of military and naval requirements. In July the President approved a bill authorizing a two-ocean navy and construction of 200 warships.

[5] Letter, LJB to Assistant CofS, Military Intelligence Division, WD, Feb. 29. 1940 (NBS Box 442, AG).

1940 under Vannevar Bush, to initiate and speed the development of new and improved instruments of war.[6]

Over the next year NDRC organized four divisions with multiple subunits to propose and direct research, in armor and ordnance; bombs, fuel, gases, and chemical problems; communication and transportation; and detection, controls, and instruments. Wholly manned by physicists, chemists, and engineers from the universities and the laboratories of industry, NDRC was authorized to originate and support military research needs and to utilize as necessary the facilities of the Bureau and other Federal agencies. At the inception of NDRC, the Bureau through Briggs' Uranium Committee had just one specifically assigned project, that of investigating "the possible relationship to national defense of recent discoveries in the field of atomistics, notably the fission of uranium." [7] It was the first of more than a score of NDRC projects assigned to the Bureau.

The mobilization of science and scientists began as the military services sent to NDRC lists of projects in which they were engaged and investigations they believed important but had not started for lack of funds or manpower. To them NDRC added projects of its own, in some cases over the early indifference or even opposition of the services. The projects were apportioned among the NDRC divisions and negotiations opened to assign them by contract to the institutions best qualified to work on them. As 1941 began, a total of 184 contracts had been recommended.[8]

Rounding out the organization of scientific research for national defense, an Executive order of June 28, 1941, established the Office of Scientific Research and Development (OSRD). Vannevar Bush, NDRC chief, moved up to OSRD as James B. Conant assumed direction of NDRC. OSRD extended the range of research beyond weaponry to include medicine. With enlarged authority it was also better enabled to correlate NDRC research and that undertaken by the military services themselves and, with the need to accelerate the atomic bomb program, to bridge the gap between research and procurement of the device.[9]

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[6] Irvin Stewart, Organizing Scientific Research for War (OSRD, Science in World War II, Boston: Little, Brown, 1948), pp. 3–7. The Council of National Defense, created in 1916 "for the co-operation of industries and resources for the national security and welfare," consisted of the Secretaries of War, Navy, Interior, Agriculture, Commerce, and Labor.

[7] Ibid., p. 19.

[8] Ibid., pp. 18, 20. For the negligible impact on the military of technological advances up to 1940 in weaponry, radio, radar, and aviation, see Reinhardt and Kintner, The Haphazard Years, pp. 131 ff.

[9] As finally reorganized in December 1942, NDRC consisted of 19 divisions, in almost all of which the Bureau had some degree of involvement: Ballistic research; effects of impact and explosion; special projectiles and rocket ordnance; ordnance accessories; new

Largely as a consequence of the assignment of NDRC projects, many of them of a classified nature, the annual report of the Bureau for 1941, for the first time, declared its contents restricted to nonconfidential research. A year later so much of Bureau work was classified that further publication of the report became pointless. Equally valid perhaps was the reason offered by the Department of Commerce, that printing of the reports would cease in order to effect savings of paper, manpower, and printing funds.[10]

The open reports for the years just prior to the war identify the preliminary stages of many of the Bureau's later investigations. The last reference to Bureau work on heavy water, for example, appeared in the report for 1939, describing the preparation in the cryogenic laboratory of pure deuterium (D_2), for measurement of its properties at the Bureau and at Columbia University. The substitution of deuterium oxide (D_2O) for part of the water in standard cells was also noted, the difference of drift between cells with normal and heavy water providing a check on the constancy of the standard cell.[11]

Still unclassified in 1939 was the intensification of work on the paraffin hydrocarbons, in search of an optimum synthetic aviation fuel. (The next annual report, more wary perhaps, emphasized the antiknock characteristics of these hydrocarbons in automotive engines.)

The formation of the Interdepartmental Screw Thread Committee, a joint War, Navy, and Commerce Department board, was reported in 1940, to

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missiles (of which Hugh L. Dryden was a section chief directing an investigation of jet propulsion and certain guided missile research); subsurface warfare; fire control; explosives; chemistry; absorbents and aerosols; chemical engineering; transportation development; electrical communication (of which J. H. Dellinger headed the radio propagation section); radar; radio coordination; optics; physics; war metallurgy; and miscellaneous weapons. The Bureau was also concerned in three of the five OSRD panels outside the divisions: Applied mathematics, vacuum tube development, and radio propagation. Ibid., pp. 84–97.

Considerable Bureau wartime research was done under NDRC and OSRD auspices, and as a consequence the reports and correspondence relating to that research are to be found principally in the OSRD records now stored in the National Archives. See General Records of OSRD, Transfer of Funds—NBS, in NARG 227, and Master Subject Index, Summary Technical Reports of NDRC. Wartime research for NACA and for the Navy and War Departments was reported directly to these agencies, the reports and records maintained in their files.

[10] A typescript of the annual report for 1943, containing open material only, and with the Commerce note on suspension of publication, is available in NBS Box 482, PRA. An MS annual report for 1944 is in NBS Box 494, PRA. None has been found for 1945 except that portion prepared by the division of weights and measures, in NBS Box 506, PRA.

[11] NBS Annual Report 1939, pp. 51, 53.

make mandatory the interchangeability of parts in industries retooling under educational orders. New research had begun on fire-detection and fire-extinguishing equipment for airplane engines, on better aircraft metals, and on vibration problems that had arisen as airplane engine weights decreased and speeds increased. Optical glass production had gone up sharply, in order to provide an emergency reserve.[12] And "as part of the national defense program," an extensive survey was begun of all standardization, simplification, and code activities of the Nation's technical societies and trade associations, looking to a complete revision of the Bureau's National Directory of Commodity Specifications.

Among the progress reports on the hundreds of projects on which the Bureau had been working during the past decade, the 1940 annual report made special note of the successful preparation of an iron with less than 0.01 percent impurities. This nearly elemental iron was expected to permit better determination of the fundamental properties of the metal than ever before possible.[13] A new investigation was begun that year for the bone char industry in the production of bone char and vegetable carbons. Although the use of bone char for clarifying and decolorizing raw sugar was several centuries old, virtually no fundamental data existed on the functioning of decolorizing media. The exploration of techniques for determining the characteristics of the raw materials, the principles of decolorization of bone char, and bone char revivification continued through the war years and after.[14]

Reported at length that year was the first tabulation of results of an investigation begun in 1936 of truck-weighing scales. As the Bureau had been called on to determine the inequities of commercial weights and measures in 1910, railroad car scales in 1915, and mine scales in 1918, so in the thirties Bureau surveillance of the trucking industry was sought as the juggernauts of the highway began to overtake the railroads in moving pro-

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[12] The Bureau was awarded a contract by the Procurement Division of the Treasury Department in November 1939 for 11,400 pounds of optical glass as a national reserve, with the request to keep confidential the fact that the glass was for Army aerial camera lenses and Navy binoculars. Monthly Report, LJB to Secretary of Commerce, November 1939 (NBS Box 440, PRM); memo, R. T. Stull for E. C. Crittenden, February 21, 1940 (NBS Box 442, AG). After Pearl Harbor, all optical glass production became a classified project.

[13] RP1226 (Thompson and Cleaves, 1939) and RP1472 (Cleaves and Hiegel, 1942) described the preparation and properties of the iron. By 1949 the Bureau was preparing 5-pound ingots of the iron so pure that detection of aberrations "constituted a major problem" (NBS Annual Report 1949, p. 47).

[14] NBS Annual Report 1940, pp. 71–72; Annual Report 1948, p. 219.

duce and other commodities across the Nation.[15] Testing more than 400 commercial truck-weighing scales in the first year of its inquiry, the Bureau found 80 percent of them with errors exceeding the agreed on allowable tolerance. Moving from State to State with its test vehicle, Bureau inspectors consistently reported three out of four scales with excessive errors, and partly as a result of these errors, a dangerous prevalence of overloaded trucks. The 5-year program was completed in 1941 when all 48 States had been visited and their State and local agencies supplied with the inspection data collected by the Bureau and its specifications for proper test equipment and procedures.[16]

Still not deemed matters of secrecy in 1941 were references to shortages of strategic materials, the acquisition of stores of quartz crystal, and Bureau work in substitute materials.

Among the first metals declared critical were aluminum, zinc, and tin, forcing industry to turn to porcelain-enameled iron for roofing and siding and for kitchen and bakeshop utensils. New technical specifications for Army and Marine Corps canteens, mess plates, and other ware made of enameled iron followed Bureau studies of their weather resistance and impact and torsional resistance.[17] Investigations were also made in the stress-strain properties of stainless steel as a substitute for aluminum alloy in aircraft production and in airplane firewalls and cowlings.[18]

While stainless steel (soon to be in critical supply too) proved in some instances an acceptable substitute for aluminum alloy and enameled iron had its uses, their limitations did much to foster the plastics industry, then in its infancy. In 1936, a year after the establishment of its plastics section, the Bureau prepared a comprehensive survey of the young industry.[19] By 1941 sufficient knowledge was available to set up emergency specifications utilizing plastics in place of scarce metals in many Government purchases. With Navy and NACA funds, research began on the properties and fabrication of these strong lightweight materials, and tests were made of their use as metal substitutes in such aircraft accessories as windshields and transparent enclosures. Utilization of the synthetic resins, as

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[15] The investigations into weights and measures and railroad car scales are described in chs. II and III. In testing mine scales in 1918, the Bureau did not find a single scale —upon which the wages of coal miners were based—even approximating the reasonable tolerance set by the Bureau, and one scale for weighing loads of less than 2 tons was found out of balance by the extraordinary error of 616 pounds. NBS Annual Report 1918, p. 29.

[16] NBS Annual Report 1937, p. 62; Annual Report 1941, pp. 67–68.

[17] NBS Annual Report 1941, p. 80; Annual Report 1942, p. 120.

[18] NBS Annual Report 1941, p. 74; Annual Report 1942, p. 118.

[19] C411, "Organic plastics" (Kline, 1936); Kline, "History of plastics and their uses * * *," a series of articles in Modern Plastics, vols. 17–18 (1940–41).

well as cellulose derivatives, was also investigated, for their use as protective coverings of aluminum and magnesium alloy aircraft parts.[20]

Two decades of fundamental studies in electrodeposition were available to the Bureau in 1941 when it started adapting its knowledge of plating to production difficulties brought on by metal shortages. At the urgent request of OPM and industry, tableware, guns, cartridge cases, projectiles, surgical instruments, aircraft parts, reflectors, plumbing fixtures, hardware, and other materials with their new plated surfaces or finishes came to the Bureau for study and advice on improving serviceability. The vital importance of plating was amply demonstrated in one instance where iron deposits were satisfactorily substituted for all the nickel and part of the copper normally used in the making of printing plates.[21]

Although the Bureau was conducting little work besides testing for the War Department in the early months of 1940, by July the number of confidential projects for the services, assigned through NACA and NDRC, had so increased that Dr. Briggs felt it necessary to obtain permission to close the laboratories to all but official visitors.[22] The next year, with a special appropriation of $21,000, work started on fencing in the Bureau grounds, guards began their rounds, and plans were made to close off the public thoroughfare, Van Ness Street, that ran through the Bureau site.[23]

By December 1941 fully 90 percent of the Bureau staff was engaged in war research. Not long after, the grounds were declared a "prohibited zone," under patrol by the Military Police.[24] Thus the Bureau was already on a war footing when the attack on Pearl Harbor made the United States a full-fledged belligerent.

Under the first shock of war, apprehension arose that enemy air fleets might attack either of our coasts without warning. Calmer heads doubted the likelihood of 3,000-mile air sorties but encouraged both blackouts and brownouts, knowing that the brightly lit coastal cities provided illumination against which ships well out to sea might be made visible to prowling enemy submarines. The Bureau assisted in the joint Army-Navy program to determine the characteristics of sky glow from artificial sources and the extent to which sky glow and shore lights might aid hostile ships offshore. It also worked with the War Department to establish requirements in blackouts, particularly with respect to street lighting, buildings, and highway movement. Even the blackout of the railroads, in force abroad, was studied, though never resorted to here.

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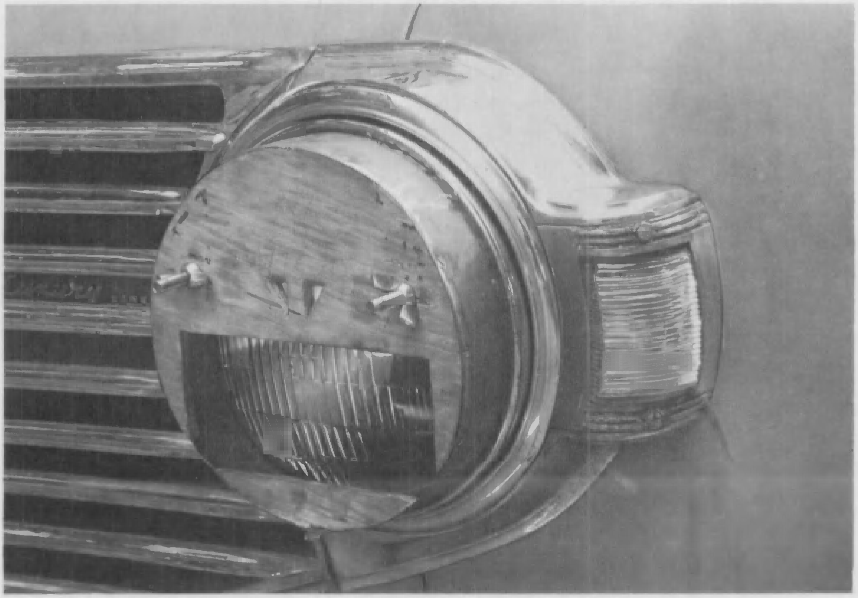
[20] NBS Annual Report 1941, pp. 77-78. See below, p. 422.

[21] NBS Annual Report 1941, p. 74; Annual Report 1942, p. 114.

[22] Memo, LJB to Acting Secretary of Commerce, July 10, 1940 (NBS Box 442, AG).

[23] NBS Annual Report 1941, p. 63.

[24] Hearings * * * 1943 (Jan. 12, 1942), p. 208; MS NBS Annual Report 1943, n.p.



A mockup mask devised at the Bureau for cutting the upward glare of sealed beam headlights, one of dozens of such blackout or brownout devices to reduce skyglow over the coastal cities in the first years of the war.

In the spring of 1942 the Office of Civilian Defense instituted dimouts and blackouts in full force. At the request of OCD, the Bureau tested textiles and paper as blackout materials, devised masks to eliminate upward light from automobile headlights, improved Army blackout headlamps, and determined the acoustic properties of suitable air-raid alarms, including sirens, steam and compressed-air whistles, and loudspeakers. A Bureau letter circular went out to city and town authorities on alarm systems they might set up with available materials, and an "Air Raid Protection Code for Federal Buildings" was distributed to Federal offices throughout the country.[25]

The construction of Army camps, bases, and temporary Government office structures that began with passage of the Selective Service Act went into high gear after 1941. The Bureau's building specifications for their fabrication saved much vital material. (Labor costs were something else again.) In the stress of the emergency, glaring deficiencies in building codes that had resisted Bureau efforts at change were rectified by Federal edict,

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[25] NBS Annual Report 1942, pp. 110, 115; Lyman J. Briggs, NBS War Research: the National Bureau of Standards in World War II (September 1949), pp. 103–104 (hereafter cited as NBS War Research); LC685, "Devices for air raid warnings" (1942), superseded by LC706 (1942).

accomplishing, the Bureau noted wryly, long overdue "legitimate economies." New knowledge of construction, for example, had made obsolete the use of 2 x 6 beams in roof rafters, where 2 x 4's were more than adequate, and multiplied by tens of thousands of buildings saved forests of precious wood.[26]

Time, labor, and material-saving studies available in the Bureau's building and housing studies had long urged the use of precast concrete flooring, of prefabricated wood and sheet-steel frames, walls, floors, and roofs, of metallic roofing materials, and of fiber and plywood paneling as insulation materials. These as well as the elimination of nonessentials and substitution of less scarce or noncritical materials were to find their way into defense housing projects through new building code requirements.[27]

The greatest inertia in the building world, adding disproportionately to construction costs and most prodigal of labor and materials, was in plumbing. Bureau research since the 1920's on plumbing practices and plumbing hardware had little impact until the war, when a new manual, designed to save "thousands of tons of critical metals," became the basis for emergency plumbing standards made mandatory in all Federal construction.[28]

The shift from educational orders to all-out war production almost immediately quadrupled Bureau testing and certification of measuring instruments and apparatus, particularly of the precision gage blocks that served as master standards in the production and inspection of war materials. Within 6 months Army Ordnance set up 13 district gage laboratories across the country to serve gage manufacturers, and established gage test facilities at all its arsenals turning out guns and shells. The need for enormous quantities of the blocks led to their hasty manufacture by inexperienced firms, forcing the Bureau to reject large numbers of seriously inaccurate or defective sets before its standards were met.[29]

Early wartime tasks with high priority assigned to the Bureau included investigations in the conservation of petroleum, in the production of synthetic rubber, and the testing and stockpiling of quartz crystals. The concern in the twenties over America's dwindling petroleum resources waned with the discovery of new fields in the Americas and the importation of oil from the Caucasus and the Middle East. The flood of oil created a vast new industry and by 1940 propelled more than 32 million automobiles, buses, and trucks over the Nation's roads. But as oil tankers became prime targets of enemy

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[26] Hearings * * * 1941 (Dec. 9, 1939), pp. 122, 124.

[27] NBS Annual Report 1941, p. 85; Annual Report 1942, pp. 125–127; BMS88, "Recommended building code requirements for * * * war housing" (1942).

[28] Ibid., and BMS66, "Plumbing manual" (1940).

[29] NBS Annual Report 1942, p. 107.

submarines, the supply tightened. Gasoline rationing became severe, however, not so much to save gas as to conserve the rubber in automobile tires.

Convinced by their ration cards that the critical shortage was in gasoline, inventive citizens besieged the Office of the Petroleum Coordinator with gas-saving devices. Almost a hundred of their expedients came to the Bureau for assessment, among them naphthalene fuel dopes, air bleeds or "squirrel cages" in the intake manifold, speed governors in the fuel line, a vacuum gage calibrated to read miles per gallon, and a variety of attachments to the exhaust line—all interesting but not to the purpose.[30]

Far more critical was rubber. Cut off from natural rubber resources by the Japanese conquests in the Pacific, this country began all-out development of synthetic rubber. With precision techniques learned in the 1920's on isoprene when it was a laboratory curiosity, the Bureau was to supply endless measurements of the thermodynamic properties of artificial rubbers and their basic materials, data vital to their manufacture.[31]

As crucial in wartime as petroleum and rubber was a component of radio whose supply was endangered because it had to be imported. That was the wafer-thin quartz crystal, a silicon dioxide formed in the earth under pressure, whose piezoelectric property made it possible to hold radio transmission and reception to a precise frequency. As the heart of all radio apparatus, huge quantities of the crystal were to be needed in the radio communication apparatus of the armed forces in everything from walkie-talkies to radar, as well as in the warborn realm of electronic equipment.

The best quartz crystal was mined almost exclusively in Brazil, and when attempts to produce an artificial crystalline quartz met with only fair success, large-scale importation and stockpiling of the crystal began. Charged with examination and certification of the raw material, a special unit in the optical division of the Bureau by 1942 was testing 75,000 pounds of raw crystal per month, of which approximately a quarter proved suitable for making radio oscillators.[32]

As war approached in 1941, Congress appropriated $100,000 to enlarge the optical glass plant at the Bureau and $230,000 for a permanent radio laboratory at Beltsville, Md., to replace the wooden structure destroyed by fire the previous November. With the acquisition of more powerful radio equipment at the Beltsville laboratory, transmission of standard radio and audio frequencies and other services was extended so that good reception was possible throughout the United States and fair reception over most

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[30] NBS Annual Report 1942, p. 110.

[31] Ibid., pp. 116–117. The synthetic rubber program is described on pp. 411–412.

[32] NBS Annual Report 1942, p. 111. For more on the crystal program, see pp. 408–410.

of the world.[33] Lost to the Bureau was the expanse of open fields (scarce in the Washington area) on which the radio propagation research laboratory at Meadows, Md., was situated. It was requisitioned in 1942 for the construction of Andrews Air Force Base, and the laboratory moved its recording equipment to new structures at Sterling, Va.

On the 12.5 acres of "Pembroke Park" that the Bureau acquired in 1942, adjacent to the west and north of its Washington site, Congress authorized construction of a new and much needed Materials Testing Laboratory. It was completed in April 1943 at a cost of $600,000. Erection of a 6-foot wind tunnel for bomb and projectile research completed the wartime construction at the Bureau under direct appropriations.[34]

The war saw virtually no change in the organizational structure of the Bureau beyond creation of a special projects section for work on guided missiles and a new division for proximity fuze and other ordnance research. The staff of 950 in 1939 rose to 1,204 by mid-1941. Two years later it totaled 2,263, including over 200 in uniform, and approximately that level was maintained to the end of the war.[35]

More spectacularly, total working funds, direct and transferred, which reached a new high—in excess of $3 million—in fiscal years 1940 and 1941, soared to $7½ million in 1942, and to their peak of $13½ million by 1944. In 1940 transferred funds had been one-sixth of regular appropriations to the Bureau. A year later, with NDRC and service assignments, they were one-half, and by 1944 had grown to almost twice the amount of direct appropriations.[36]

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[33] Memo, LJB for Acting Secretary of Commerce, July 10, 1940 (NBS Box 442, AG); NBS Annual Report 1941, p. 65; Science, 98, supp. 8 (1943); Science, 101, supp. 10 (1945).

[34] NBS Annual Report 1941, p. 61; Annual Report 1942, p. 103; MS Annual Report 1943, n.p. With the Thom estate, known as "Pembroke Park," the Bureau site comprised 67.8 acres. The estate is described in Hearings * * * 1940 (Apr. 21, 1939), pp. 184–186. The new wind tunnel, authorized in 1943, was completed at a cost of $110,000 2 years later. See G. B. Schubauer, MS "History of the Aerodynamics Section," March 1956 (NBS Historical File). Other construction, under transferred defense funds, included a number of Quonset huts, enlargement of the glass plant, storage and laboratory facilities for the quartz program, and new quarters for the ordnance (proximity fuze) project. Except for the main ordnance building and the addition of a story to the Far West building, all were temporary structures.

[35] MS Annual Report 1943. Of the 2,372 on the Bureau staff in 1944, directors and supervisors numbered 116, research scientists 679, laboratory assistants 576, and clerical, mechanical and other workers 901. Report to the Senate Subcommittee on War Mobilization, Apr. 13, 1944 (NBS Box 489, AGL).

[36] See app. F. The agencies supplying transferred funds in 1942–44, as well as the amounts and in some cases the identity of the projects, are reported in NBS Box 464, AG; Box 477, AG and FP; and Box 489, AGL.

By February 1943, Dr. Briggs reported, the entire staff and facilities of the Bureau were wholly engaged in war work. All conference and lecture rooms had been converted to laboratories, and double and triple shifts were in effect in some sections to make maximum use of space and equipment. The prewar 39-hour week had long since been extended to 44 hours and no overtime pay was permitted.

The rising cost of food, clothing, and rent worked some hardship, but almost everyone at the Bureau subscribed 10 percent of his salary for war bonds. All worried about the 5 percent Victory tax and new income taxes to come, considering their prewar civil service salaries. And because of the pay, the Bureau had had to recruit boys too young for the armed forces as shop assistants and for training as mechanics and instrumentmakers. With few exceptions, they were lost within a year or two to the defense industries.[37]

Within a year after the war began, Dr. Briggs was to recall, "just about everything at the Bureau was classified." The tight security thrown around the work in the laboratories became constricting at times, and on occasion Dr. Briggs felt he had to exercise some discretion. But that discretion did not extend to anything connected with the research on the atomic bomb.[38]

THE BUREAU AND THE ATOMIC BOMB

Under the direction of Dr. Briggs during the first 2 critical years of its inception, the work that led to the atomic bomb grew thereafter beyond the powers of the Uranium Committee to control. It became a technological feat, stretching the capabilities of the greatest concentration of the Nation's scientists and engineers ever assembled. The massive requirements for final production had to be lodged eventually in the vast anonymity of the military establishment.

The Bureau staff was engaged in scores of other fundamental investigations in physics, applied mathematics, chemistry, and engineering for the immediate prosecution of the war and few more than 60 members gave full time to the bomb program. Apart from special assignments at Oak Ridge and at Los Alamos, most of the Bureau participants carried out their work in the Washington laboratories. The Bureau was nevertheless to serve to the end of the war as "a central control laboratory for determining the purity of uranium and other products * * * used," that work, it was said,

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[37] Letter, LJB to Department of Commerce, Aug. 11, 1942 (NBS Box 464, AP); letter, LJB to chairman, Senate Commission on Appropriations, Oct. 15, 1942 (ibid., AG); Hearings * * * 1944 (Feb. 26, 1943), p. 77.

[38] **Interview with Dr. Briggs, Nov. 1, 1961.**

"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." [39]

This, of course, was not entirely so. Even before the close of the photoelectric phase of the proximity fuze project in 1943, when most of that group were sent out to Los Alamos, many at the Bureau suspected or knew generally that some kind of new weapon using uranium was under development. Yet so weighted was the wrap of secrecy that even some directly involved in research on "Tuballoy," the Briticism adopted by the Bureau as the code name for uranium, had no inkling of the real purpose of their research.[40] Wholly engrossed in his determination of the energy states of uranium, one member of the Bureau recalls thinking that the metal might be for a new type of small power plant, possibly for airplanes, to enable them to carry bigger bomb loads, or for submarines, in order to carry a larger store of torpedoes. "The last thing in the world I thought the uranium could be used for was in a bomb," he was to say.[41] The story of that secret research bears retelling.

In the year after verification in this country of the splitting of the uranium atom, Enrico Fermi sought to demonstrate a chain reaction in natural unconcentrated uranium. His colleague at Columbia, John R. Dunning, was investigating the two isotopes of uranium, the rare 235, less than 1 percent of the natural element, and the abundant isotope 238, comprising 99.3 percent of the element. In March 1940, Dunning conclusively demonstrated that U^{235} was the isotope that fissioned with slow neutrons.[42]

That same spring Edwin M. McMillan and Philip H. Abelson at the University of California made an even more spectacular discovery, that neutron absorption by U^{238} resulted in two new elements with atomic numbers 93 and 94. They were named neptunium (Np) and plutonium (Pu). Study of the latter indicated it was probably as fissionable by thermal (slow) neutrons as U^{235}. So nebulous was the "bomb project" at that stage, however, that further investigation of plutonium was delayed while McMillan went off to MIT to work on a more pressing matter, radar.[43]

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[39] Briggs, NBS War Research, p. 8.

[40] "Tuballoy" came from "Tube Alloys," the meaningless and unintelligible expression used by the British for their uranium bomb program.

[41] Interview with Dr. Carl C. Kiess, May 1, 1964. For Harold Urey's similar reaction concerning his heavy water research, see ch. VI, p. 359n.

[42] Hewlett and Anderson, The New World, 1939–1946: A History of the United States Atomic Energy Commission, pp. 13–14, 22.

[43] Ibid., pp. 33–34; McMillan and Abelson, "Radioactive element 93," Phys. Rev. 57, 1185 (1940). The discovery held out the possibility that element 94 could be produced in a pile and then separated chemically, without the tremendous expense of building isotope separation plants. Moreover, if plutonium was fissionable it would utilize all but a small fraction of the metal in a natural uranium pile.

With attention focused on the work at Columbia, three crucial questions confronted Dr. Briggs and his advisory committee in the early summer of 1940: (1) Were there any circumstances under which a chain reaction could actually be achieved? (2) Could the isotope 235 be separated on a large scale? (3) Could moderators such as graphite or heavy water and other materials be obtained of sufficient purity and in sufficient quantity? [44]

The possibility that deuterium (heavy water) might be a better moderator of a chain reaction than graphite was not overlooked. The British were convinced that a chain reaction would go in relatively small units of uranium and heavy water, and in February 1941 Urey at Columbia began investigating methods for large-scale concentration of deuterium.[45] Although heavy water proved more effective than graphite in slowing down neutrons and showed a smaller neutron absorption, its high efficiency in much smaller quantities than graphite was outweighed by the difficulties of producing useful amounts. Subsequent experiments with a uranium and heavy-water pile demonstrated that such a pile could not be shut down as completely or as rapidly as the graphite pile. Important as heavy water was in later nuclear weapons research, and in scientific, biological, and industrial research, it played little part in the wartime achievement.[46] Procurement, therefore, centered on graphite.

A group at the Bureau under Clement J. Rodden at once started work on methods of analysis for the development of a highly purified graphite. Because of the strong neutron-absorbing characteristics of the boron found in the commercial product, a graphite low in boron was absolutely essential. The work of Rodden in devising a reliable method for boron determination, later successfully applied to boron in uranium as well, enabled carbon manufacturers to produce a much more highly purified graphite. By the middle of 1942 this problem was essentially solved.[47]

Two investigations into the possibility of separating the isotopes of uranium started in the fall of 1940. At Columbia a group under Dunning

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[44] Smyth, Atomic Energy for Military Purposes (Smyth Report), p. 55.

[45] A fine summary of British encouragement of and contributions to the project appears in Groves, Now It Can Be Told, pp. 406–408. See also report of the Directorate of Tube Alloys, Statements Relating to the Atomic Bomb (London: Her Majesty's Stationery Office, 1945), pp. 13 ff; its summary in Rev. Mod. Phys, 17, 472 (1945); and Margaret Gowing, Britain and Atomic Energy, 1939–1945 (London: Macmillan, 1964).

[46] Smyth Report, pp. 95, 147–149, 153. In July 1942, marking the genesis of the hydrogen bomb, Oppenheimer first disclosed the theoretical calculations of his group at California indicating "that a much more powerful reaction than nuclear fission might be produced by the thermonuclear fusion of deuterium, the heavy hydrogen isotope," and therefore "the possibility of a * * * weapon using a more easily attainable material" than U^{235} or U^{238}. Hewlett and Anderson, p. 104.

[47] Smyth Report, p. 95; NBS War Research, p. 8.

initiated research in a gaseous diffusion method for the separation and concentration of U^{235}. At the Bureau, Philip H. Abelson of the Carnegie Institution attempted separation of the two isotopes by thermal diffusion of uranium hexafluoride, the only gaseous compound of uranium. Although an exceedingly corrosive material, the hexafluoride was workable because it was stable as a liquid at slightly elevated temperatures and moderate pressures. Abelson's work, carried out with Navy funds, was transferred to larger facilities at the Naval Research Laboratory in the summer of 1941.[48]

Efforts made in the Bureau laboratories and at Westinghouse and General Electric to find a method for manufacturing uranium powder or pure ingots progressed slowly and the Columbia group turned to the processed ore, uranium oxide, which was available in small quantities from Canada. It was evident that both Fermi's uranium pile and isotope separation depended upon obtaining uranium in a highly purified metallic form or at least as a highly purified uranium oxide. The problem came to the Bureau, and in the summer of 1941 a group under James I. Hoffman found that ether extraction of uranium oxide after conversion to uranyl nitrate removed virtually all impurities from the oxide.[49]

As a final step in the production of uranium metal, determination and analysis had to be made of the residual boron content of the reconverted oxide. Studies by Bourdon F. Scribner and J. A. Scherrer opened the way to subsequent reduction of the boron content, by reaction with calcium hydride. After months of experimentation, their coworker Clement Rodden distilled an extremely pure calcium making this last step possible. The ether extraction and boron reduction processes, as effective with pitchblende and carnotite ore concentrates as with uranium ores, became standard procedures in the purification of all uranium used in piles.[50]

The winter of 1940–41 was a time of decision. Besides the investigations in gaseous and thermal diffusion methods for isotope separation, Jesse W. Beams at Virginia was working on a centrifuge process and Ernest O. Lawrence at California on electromagnetic methods of separation. While Dr. Briggs felt that quantity separation of isotopes was important from a military standpoint as probably the only way to a chain reaction in a mass small enough for a bomb, separation would be difficult and expensive. Pilot plant construction ought therefore to wait until further studies disclosed the most promising method. Characteristically, his real interest was in power

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[48] Both the thermal and gaseous diffusion processes were to be used in the large-scale plants for the production of U^{235} at Oak Ridge, the gaseous method eventually proving the more efficient of the two.

[49] Hewlett and Anderson, pp. 28–29, 86; Smyth Report, p. 93; NBS War Research, pp. 8–9.

[50] Hewlett and Anderson, pp. 66, 87; NBS War Research, p. 9.

production and not a bomb, and therefore in the uranium-graphite experiment and in quantity production of heavy water, which might go better in a pile.[51]

The cautious progress of the bomb project under Dr. Briggs's advisory committee was apparent in the meager funds and the assignment of them proposed in July 1941. The committee recommended grants of $167,000 for a pilot plant to produce heavy water for Fermi's chain-reaction studies, $95,000 for the centrifuge work on elements 93 and 94, $25,000 for gaseous-diffusion experiments, $10,000 for other isotope separation studies, $30,000 for investigation of the chemistry of uranium compounds and studies of separation methods, and just $8,000 for an investigation of element 94, plutonium.[52] The total was $2 billion short of the final cost of the first atomic bomb.

So far as the general public was concerned, the shroud of secrecy that descended after 1940 on what the President called "atomistic research" was almost absolute. The single letter on the subject from an inquiring citizen found in Bureau files was wide of the mark. The reply was more pertinent. In June 1941 a man in Meredith, N.H., wrote to the White House protesting an unnamed scientist's claim that with the smashing of the atom the time would soon come when "every householder would be able to store a thousand years' fuel supply in his cellar." The New Hampshire man saw nothing but disaster in this enormous power confined in his home or, more dangerously in the possession of unfriendly persons, and sought reassurance.

Dr. Briggs's personal reply to the letter, which had been sent on from the White House for an answer, was only vaguely comforting. It also reflected something of his own feeling at the time. There was no need, he wrote, "to feel unduly alarmed about smashing atoms. Up to the present time at least this has been accomplished only by putting into the system as a whole a great deal more energy than can be got out of it." [53]

Although production of Lend-Lease equipment and munitions mounted month by month and such priority projects as radar and rockets, the proximity fuze, and new air, surface, and subsurface weapons progressed, no comparable signs of achievement sustained the physicists working on the bomb. British reports in the spring of 1941 that the Germans were producing heavy water in quantity in Norway and were acquiring materials that could only be used in work with uranium prompted demands for greater effort and more results. The fear grew that time was running out.

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[51] Hewlett and Anderson, pp. 37, 40; James P. Baxter, Scientists Against Time, p. 425.

[52] Hewlett and Anderson, p. 40.

[53] Letter, LJB, June 17, 1941 (NBS Box 455, IPXA). Cf. Leo Szilard's statement in a letter of Jan. 25, 1939, that the possession of atomic energy is not "very exciting * * * if the energy output is only two or three times the energy input." Quoted in Lewis S. Strauss, Men and Decisions (New York: Doubleday, 1962), p. 172.

Partly in order to accelerate the contract research on uranium projects initiated by NDRC and provide better coordinated direction, OSRD was established in June 1941, with direct access to the President. Urgently required was information on the critical mass of a U^{235} bomb, design data on a gaseous diffusion plant for large-scale separation of uranium isotopes, and assessment of a heavy-water pile. Apart from the NDRC assignments of the Advisory Committee (now OSRD's S–1 Section), at the direction of OSRD the problem of large-scale uranium isotope separation was turned over to groups under Lawrence and Urey, and that of production of element 94 (plutonium) to Compton's group at the new and cryptically named "Metallurgical Laboratory" at the University of Chicago.[54]

By the end of 1941 research groups at Columbia, Princeton, Chicago, California and elsewhere had achieved considerable basic knowledge of nuclear properties and of the physical constants of the materials involved. Sufficient mathematical calculations had been made to suggest the probability that the critical size of a bomb either with concentrated U^{235} or the new element plutonium was almost certainly within practical limits.[55] On the other hand, Fermi had constructed an experimental graphite and uranium pile at Columbia but no chain reaction had been achieved principally because of the poisoning effect of the boron in the uranium. No appreciable amount of U^{235} had been separated from U^{238}, only traces of plutonium had been produced, and the production of large quantites of uranium metal, heavy water, and pure graphite still remained largely in the discussion stage.[56]

One week before Pearl Harbor, Dr. Briggs's S–1 Section made the decision recommending a major all-out effort to construct the bomb. Eleven days after Pearl Harbor, at another meeting in Dr. Briggs's office at the Bureau, Arthur H. Compton, as head of a committee of the National Academy of Sciences, outlined the time schedule that the project must strive to meet:

> By July 1, 1942, to determine whether a chain reaction was possible.
>
> By January 1943, to achieve the first chain reaction.

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[54] Smyth Report, p. 71; Hewlett and Anderson, p. 45.

[55] If plutonium was still an unknown quantity in November 1941, it was known with some certainty that a spectacularly destructive fission bomb would result from bringing quickly together a sufficient mass of U^{235}—somewhere between 2 and 100 kg. (4.4 and 220 pounds)—although nothing like even 2 kg of the material was yet in sight (Hewlett and Anderson, p. 47). On this basis it was conjectured that from 1 to 10 tons of U^{235} would be required to construct the bombs necessary to devastate the major military and industrial objectives in Germany. Tonnage production, either by the gaseous diffusion or centrifuge method, was believed to be 3 or 4 years away (Baxter, pp. 427–428).

[56] Smyth Report, p. 73.

By January 1944, to extract the first element 94 from uranium.
By January 1945, to have a bomb.[57]

Speed became essential. To hasten decisions, the S–1 Section, grown too large for action, was reorganized in June 1942 as the S–1 Executive Committee under James B. Conant of NDRC, with Briggs, Compton, Lawrence, Urey, and Eger V. Murphree (of Standard Oil Development Co.) as members. By then, five possible approaches to bomb production had emerged holding high promise: separation of U^{235} by centrifuge, diffusion, or electromagnetic methods, and production of plutonium in a uranium-graphite or uranium-heavy water pile.[58] All were scheduled to be explored through the pilot plant stage, and all depended to a large degree on what soon became the principal function of the Bureau, the development of analytical procedures for controlling the purity of critical materials in the reactors and in the bomb.

Some of these materials required as many as 20 individual chemical analyses, and spectrographic determinations of as many as 30 elements in their raw state, before methods for refinement could be established.[59] By the end of 1945 nearly 9,000 samples of materials were to come into the Bureau laboratories and almost 30,000 separate analyses completed. Equally extensive investigations in the metallurgy and metallography of uranium were necessary, to determine, for example, the kinds of crucible materials in which uranium could be melted without contamination. Much work was also done at the Bureau toward establishing radioactivity measurements and safety procedures in handling the bomb materials.[60]

The analytical work of the Bureau was accelerated in June 1942 with the approval of funds for three pilot plants for U^{235} production and one for plutonium. The theoretical design of the plants had been accomplished and their construction assigned to the Army Corps of Engineers under the disguise of the "DMS (Development of Substitute Materials) project." In August 1942 the DMS project became the Manhattan District project, its director Brig. Gen. Leslie R. Groves.

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[57] Hewlett and Anderson, pp. 54–55.

[58] Hewlett and Anderson, p. 71.

[59] The analytic research of the Bureau was reported in the classified Manhattan District Technical Series. The few papers published by the Bureau after the war include a summary account of analysis of the U spectrum, by Kiess, Humphreys, and Laun in RP1729 (1946); the development of a highly sensitive method for spectrographic determination of 33 volatile impure elements in U-base materials, by Scribner and Mullin in RP1753 (1946); and determination of the thermoelectric properties of U, by Dahl and VanDusen in RP1813 (1947). For the work of the Bureau's mathematics group on the atomic bomb and other wartime projects, see OSRD records, NARG 227, file MTP, General Correspondence.

[60] NBS War Research, pp. 9–15; interview with William F. Roeser, Dec. 3, 1963.

If many of the scientists connected with the bomb project under NDRC and OSRD secretly hoped that some principle might emerge proving the inherent impossibility of an atomic bomb, by mid-1942 that hope was past. Theoretical possibility had become high probability, and in December General Groves entered contract negotiations for the design and construction at Oak Ridge, Tenn., of a giant industrial complex beyond anything the original members of the S–1 Committee could possibly have contemplated. The commitment had been made, and with the transfer of all OSRD contracts to the Army in May 1943, the research responsibilities of the S–1 Committee ended.[61]

By the fall of 1942 enough pure graphite, uranium oxide, and uranium metal were arriving at the Metallurgical Laboratory at Chicago from industry to justify building an actual self-sustaining chain reacting pile. Little more than 6 tons of uranium metal were at hand, just barely sufficient for the pile Fermi and his associates erected under the west stands of Stagg Field. There on December 2, 1942, the first nuclear chain reaction was produced in a system using normal uranium.

The immediate objectives of the Metallurgical Laboratory were proved, that a controllable chain reaction could be produced in unseparated uranium, and that separation of fissionable plutonium from the U^{238} in the pile was more feasible than separation of the uranium isotopes. The ultimate objectives of the laboratory still remained, to determine a process for separating the plutonium chemically from the pile, and to obtain theoretical and experimental data on a "fast neutron" reaction, such as would be required in an atomic bomb.[62]

The decision to build a pilot plant for the relatively large-scale extraction and purification of plutonium had been made in January 1942. Construction of the plant known as the Clinton Engineer Works began just above the town of Oak Ridge. The Clinton pile started operating in November 1943, its successful procedures and the data obtained in its performance guiding construction of the large-scale plant going up at Hanford, on the Columbia River, in the State of Washington. The first quantity production of plutonium, from three of the five piles at the Hanford complex, began in September 1944.[63]

On the principle that time was more important than money, and that every probability and process that offered a chance of success must be explored, a number of large-scale separation plants for U^{235} and for deuterium were ordered constructed. At least seven processes for separating uranium

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[61] Hewlett and Anderson, p. 115; Smyth Report, p. 224.

[62] Hewlett and Anderson, p. 112; Smyth Report, pp. 98–99; Baxter, p. 432.

[63] Smyth Report, pp. 106–107, 111.

isotopes had become available and two of them, the gaseous and liquid diffusion methods, were successfully pursued to the production stage.

Construction of a steam power plant for the gaseous diffusion process, one of the largest ever built anywhere, based on research at the Naval Research Laboratory, began in June 1943 at the Clinton Works. Before the summer of 1945 it was in operation, furnishing enriched U^{235} for concentration at the nearby electromagnetic plant. The plant for electromagnetic separation of uranium isotopes, based on the research of Lawrence at the Radiation Laboratory in California, had gone up at Clinton beginning in March 1943. By the winter of 1944–45 it was in operation, producing U^{235} of sufficient purity for use in the bomb.[64]

While the basic scientific and engineering research in plutonium and U^{235} had been in progress, in the spring of 1942 Gregory Breit at the Metallurgical Laboratory initiated the experimental planning on a "fast neutron" reaction such as would be required by the bomb. Almost a dozen universities, the Carnegie Institution of Washington, and the Bureau became engaged in basic mechanics and instrumentation for the project. That summer a group at Chicago under J. Robert Oppenheimer of California's Radiation Laboratory began the theoretical work on the physics of the bomb.[65]

Upon transfer of the project to the Manhattan District, search was made for a safe and secret site for the laboratory where the bomb was to be assembled. A remote mesa at Los Alamos, N. Mex., on which a handful of empty structures marked the site of a former boarding school, was found that November. In March 1943, Oppenheimer arrived to direct operations, construction of the laboratory began, apparatus from the laboratories at Harvard, Wisconsin, Illinois, and Princeton arrived, and the first of an extraordinary body of scientists and technicans, including a British group headed by Sir James Chadwick, settled in.

Drawing on research groups from almost a dozen universities, the Metallurgical Laboratory, and the National Bureau of Standards, the Los Alamos staff comprised theoretical and experimental physicists, mathematicians, armament experts, specialists in radium chemistry and in metallurgy, specialists in explosives and in precision measurement, and their technical and housekeeping assistants. Among Bureau members was the group from the proximity fuze program, drafted in the spring of 1943, and Wichers, Schoon-

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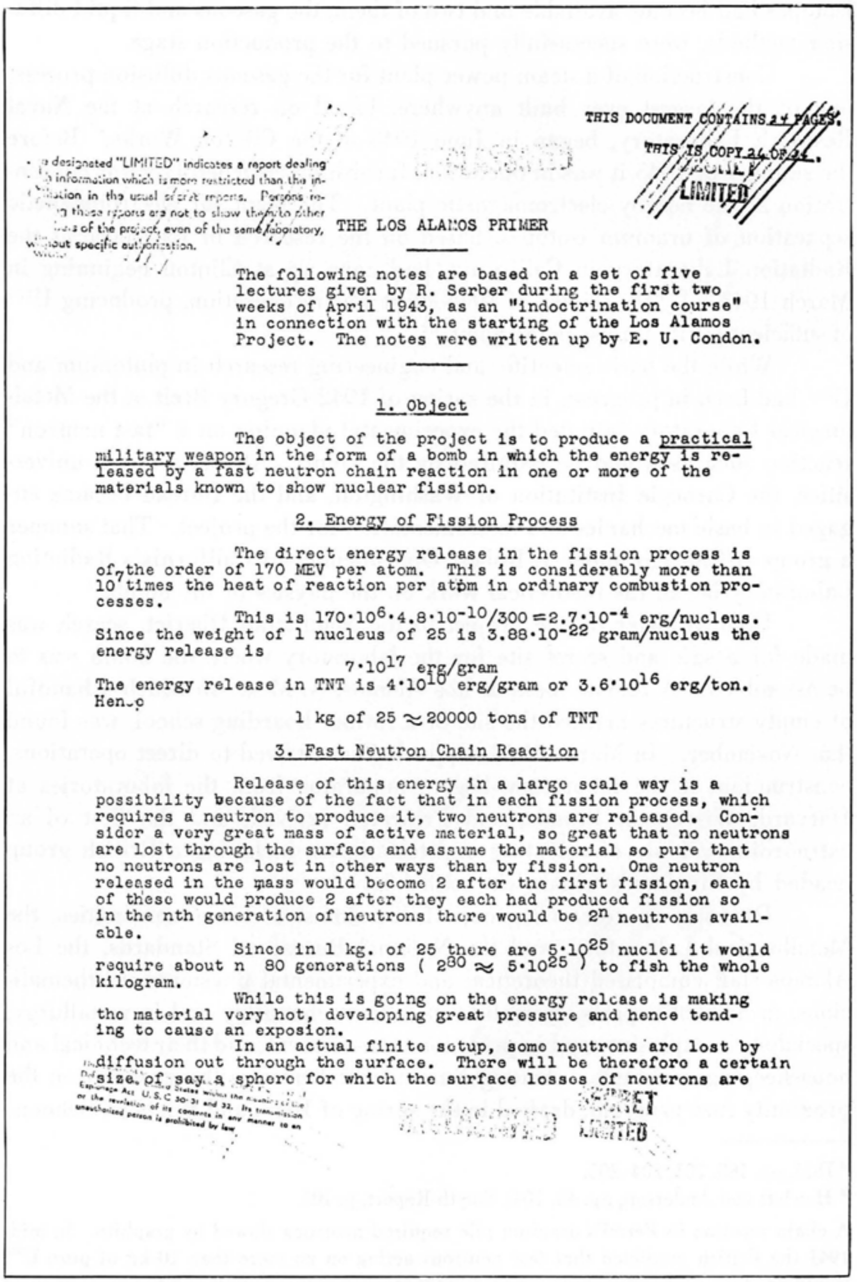
[64] Ibid, pp. 185, 201, 204–205.

[65] Hewlett and Anderson, pp. 43, 104; Smyth Report, p. 103.

A chain reaction in Fermi's uranium pile required neutrons slowed by graphite. In mid-1941 the British predicted that fast neutrons acting on no more than 10 kg of pure U^{235} would produce a chain reaction. A year later Oppenheimer, Teller, and Serber confirmed the theory of the fast-neutron reaction in U^{235} or in plutonium when sufficient quantities were brought together in a critical mass.



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THE LOS ALAMOS PRIMER

The following notes are based on a set of five lectures given by R. Serber during the first two weeks of April 1943, as an "indoctrination course" in connection with the starting of the Los Alamos Project. The notes were written up by E. U. Condon.

1. Object

The object of the project is to produce a practical military weapon in the form of a bomb in which the energy is released by a fast neutron chain reaction in one or more of the materials known to show nuclear fission.

2. Energy of Fission Process

The direct energy release in the fission process is of the order of 170 MEV per atom. This is considerably more than 10^7 times the heat of reaction per atom in ordinary combustion processes.

This is $170\cdot10^6\cdot4.8\cdot10^{-10}/300 = 2.7\cdot10^{-4}$ erg/nucleus. Since the weight of 1 nucleus of 25 is $3.88\cdot10^{-22}$ gram/nucleus the energy release is

$$7\cdot10^{17} \text{ erg/gram}$$

The energy release in TNT is $4\cdot10^{10}$ erg/gram or $3.6\cdot10^{16}$ erg/ton. Hence

$$1 \text{ kg of } 25 \approx 20000 \text{ tons of TNT}$$

3. Fast Neutron Chain Reaction

Release of this energy in a large scale way is a possibility because of the fact that in each fission process, which requires a neutron to produce it, two neutrons are released. Consider a very great mass of active material, so great that no neutrons are lost through the surface and assume the material so pure that no neutrons are lost in other ways than by fission. One neutron released in the mass would become 2 after the first fission, each of these would produce 2 after they each had produced fission so in the nth generation of neutrons there would be 2^n neutrons available.

Since in 1 kg. of 25 there are $5\cdot10^{25}$ nuclei it would require about n 80 generations ($2^{80} \approx 5\cdot10^{25}$) to fish the whole kilogram.

While this is going on the energy release is making the material very hot, developing great pressure and hence tending to cause an exposion.

In an actual finite setup, some neutrons are lost by diffusion out through the surface. There will be therefore a certain size, of say a sphere for which the surface losses of neutrons are

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The first page of "The Los Alamos Primer," reproduced in just 36 copies for key scientists and technicians on the mesa in New Mexico. An air of uncertainty, of speculation concerning the calculations, is found on almost every page of the "Primer."

over, Snow, and Gordon, brought out in January 1944 to take charge of purification of U^{235} scrap so it could be used again, and to prepare especially purified reagents for use in analyses of the uranium and plutonium.[66]

The newcomers were briefed in a series of five lectures given by Robert Serber, Oppenheimer's colleague at the Radiation Laboratory at California. The lectures were set down shortly after their delivery by Dr. Edward U. Condon (to succeed Dr. Briggs as Director of the Bureau 2 years later) in a 26-page pamphlet entitled "The Los Alamos Primer." [67]

"The object of the [Los Alamos] project," the primer began, "is to produce a *practical military weapon* in the form of a bomb in which the energy is released by a fast neutron chain reaction in one or more of the materials known to show nuclear fission." The materials were designated as 25 [U^{235}], 28 [U^{238}], and 49 [plutonium 239]. "Material 49," the primer went on, "is prepared from neutron capture reaction in 28. Only microgram quantities have so far been produced. There is another project going on presently to produce 49 for us in kilogram quantities."

On the basis of current calculations, the primer continued, "the simplest estimate of the minimum size of the bomb is a critical mass of 200 kilograms, in a sphere twice that size." Upon that assumption, "the immediate experimental problem is largely concerned with measuring the neutron properties of various materials and with the ordnance problem * * * to determine the critical size and time scale, working with large but subcritical amounts of active material."

The hazard of radiation that preoccupied every laboratory experiment and industrial process involving live material and that called on so much engineering effort in the construction of the plants also haunted Los Alamos. But the consuming concern at Los Alamos as the bomb approached realization was predetonation. The primer attempted to estimate the possibility of a premature or incomplete explosion, particularly one that might give the enemy a chance to inspect or recover the materials of the bomb.

Three sources of neutrons were recognized that might provide background giving rise to the danger of predetonation: (1) cosmic rays, (2) spontaneous fission, or (3) nuclear reactions which produce neutrons. Thus, while "there will always be some chance of predetonation," every

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[66] Twelve other members of the Bureau, including physicists, chemists, glassblowers, instrumentmakers, and metallurgists, were at other installations of the Manhattan District. Letter, LJB to War Manpower Commission, May 10, 1945 (NBS Box 502, AP).

[67] Thirty-six copies of the primer, classified "Secret—Limited Circulation," were mimeographed for the use of key members of the project. Quotations here are from Dr. Condon's personal copy. The primer was declassified on Feb. 25, 1963. Certain of its information is alluded to in the Smyth Report, pp. 213 ff.

calculation so far made indicated that "in any event the bomb will generate enough energy to completely destroy itself."

The thought of predetonation may have seemed somewhat remote when the lectures were first given, for in a final section of the primer that discussed the mechanics of shooting that would bring the pieces of the bomb together with the right velocity, forming a critical or spontaneously exploding mass, it was admitted that "this is the part of the job about which we know the least at present." Two years after its organization, Los Alamos had the answer.

By early 1944 fear of German success began to recede as the magnitude of the required research and industrial effort in this country became evident. Germany no longer had such resources.[68] By the spring of 1945 Oak Ridge began producing U^{235} in significant amounts and Hanford was shipping increasing quantities of plutonium to Los Alamos. The bomb was a near certainty, though no one yet knew how powerful it would be.

Only the emergency of war could have justified the cost, in excess of $2 billion, of the manmade atomic explosion that occurred on the morning of July 16, 1945. The detonation took place in a remote section of the Alamogordo Air Base, far to the south of Los Alamos. It was 10 weeks after the suicide of Hitler and the war in Europe had ended.

THE RADIO PROXIMITY FUZE (NONROTATING TYPE)

In the shadow of the atomic bomb were two other spectacular developments of World War II, the airburst proximity fuze and radar. Neither idea was new. A fuze that would explode a shell or bomb when directly over its target, rather than on impact, had been sought since World War I. The experimentation leading to radar began in Great Britain in 1919 and in this country, at the Naval Research Laboratory, in 1923.[69] The Bureau was to have little to do with radar, much to do with the proximity fuze.

An artillery or antiaircraft shell, or bomb, rocket, or mortar round with a VT (variable time) proximity fuze has from 5 to 20 times the effective-

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[68] As the defeat of Germany neared, a scientific mission somewhat ineptly named ALSOS (the Greek word for "groves"), closely followed the advancing Allied columns and sped through the laboratories and industrial plants of the occupied countries and across the Rhine, to assess the progress the Germans had made in their development of the bomb. Incredible was the discovery that nothing like a real effort had been made anywhere, owing as much perhaps to the death or flight of Germany's first-rank scientists as to Nazi ideology.

[69] In this country Dr. A. Hoyt Taylor, first superintendent of the radio division of the Naval Research Laboratory established after World War I, is credited with discovering the principle of radar by bouncing back a radio beam directed at a ship on the Potomac. Baxter, p. 139.

ness of a round fitted with a contact or pre-set time fuze. In the case of very large bombs whose damage is almost entirely due to blast and airburst almost doubles the area of destruction created by bombs with conventional fuzes.[70]

Bombing runs and antiaircraft fire with ordinary fuzes rarely achieve hits with more than 5 percent of the expenditure. Where foxholes or shallow depressions in the ground offer good protection against anything but a direct hit, even a deep foxhole gives scant protection against a projectile exploding 20 or 30 feet overhead. To get that overhead-burst effect in World War I, artillery counted on tree bursts or attempted to bounce shells off rock walls or hillsides to reach troops below. The potential increase in effectiveness and the estimate that manpower, supply, and other logistical factors were enhanced by five through possession of a proximity fuze, thus warranted almost any degree of expenditure and effort to perfect it.

The radio proximity fuze is essentially a tiny radio sending and receiving station about the size of a 100-watt light bulb. It operates by continuously sending out radio waves. When the waves approach a sizable object—a ship, plane, building or other structure, or open ground—they are reflected back to the receiver in the fuze. As the waves reach a sufficient intensity indicating their effective proximity, they operate an electronic switch that detonates the fuze and the projectile.

The British began intensive efforts to perfect and produce their proximity fuze in 1937. Remembering the zeppelin raids of the First War, they intended to use the fuze primarily as a defense against enemy bombers. Their work became known to scientists in this country in the spring of 1940, and that June NDRC assigned research for a similar fuze to the Department of Terrestrial Magnetism at the Carnegie Institution of Washington, where Dr. Alexander Ellett of the University of Iowa was working on miscellaneous ordnance components.[71] Under a working arrangement with NDRC, Ellett brought the problem to the Bureau, where the team of Diamond, Hinman, and Astin, which had constructed the radiosonde and radiotelemeter, was most familiar with principles that might be adapted to the fuze.

By November 1940 NDRC had determined that two types of radio proximity fuze were needed, one for rotating projectiles, sought by the Navy

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[70] Statistical data based on Army and Air Force field tests with radio and conventional fuzes, and agreeing with British findings, indicated these ranges of comparative effectiveness. [Wilbur S. Hinman, Jr.] The Radio Proximity Fuzes for Bombs Rockets, and Mortars (pamphlet of the Ordnance Development Division, NBS, 1945), pp. 5, 31–34 Hereafter cited as Hinman. See also Harry Diamond, "The radio proximity fuze," Natl. Radio News, 11, 16 (1945).

[71] Liaison with the British fuze development groups began in August 1940 and continued to the end of the war. See John S. Rinehart, MS, "Administrative history of Division 4, NDRC" (November 1945), p. 224 (author's copy). Hereafter cited as Rinehart MS.

for the antiaircraft guns protecting their ships; another, nonrotating, for Army and Air Force weapons, specifically for bombs and rockets and, later, for mortars. The radio fuze for rotating projectiles was assigned to a group headed by Merle A. Tuve and Lawrence A. Hafstad in the Department of Terrestrial Magnetism. Its final development was carried out at the Johns Hopkins Applied Physics Laboratory. That for nonrotating projectiles was transferred to the Bureau under Ellett, where Diamond and Hinman's group worked on the nonrotating radio fuze, a group under Dryden investigated an accoustic fuze, and Mohler began studying components of a photoelectric fuze.[72]

By early 1941, through the application of radiotelemetering techniques, Lauriston S. Taylor and Astin had demonstrated that acoustic fuzes were not practicable. They then joined the photoelectric fuze group under Dr. Joseph E. Henderson at the Carnegie Institution, and upon transfer of that group to the Bureau, Astin took over as director. The transfer was effected with the creation of OSRD in June 1941, when Diamond became chief of the radio and photoelectric fuze groups at the Bureau and Ellett the NDRC contracting officer.[73]

The basic principles of the rotating and nonrotating fuze were similar except that the antiaircraft shell fuze had to withstand being fired from a gun. Its stability in flight resulted from its rotation, whereas the bomb and rocket fuze produced at the Bureau had to depend upon fins. And unlike the shell fuze, the bomb fuze had to operate at wide ranges of temperature, including the extreme cold (down to $-40°$ F) encountered at high altitudes.

The group of eight that began work on the fuze on December 28, 1940, was to draw on staff members from many of the other Bureau laboratories and on scientists and technicians from university and industrial laboratories all over the country. In the last 2 years of the war, with the assignment of Army and Navy groups for testing and production, over 400 persons were engaged in the Bureau project alone.[74]

The original assignment of the Bureau was to develop a fuze that would set off a rocket attached to a bomb when the bomb had fallen within several hundred feet of a battleship. By this means, the bomb was expected to attain impact velocities high enough to penetrate and sink the ship. Much too complex and specific for the state of knowledge at the time, this requirement gave way to design of a general purpose proximity fuze.[75]

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[72] Rinehart MS, pp. 200–204: Baxter, pp. 226–227.

[73] Rinehart MS, p. 15.

[74] Hinman, pp. 41–47, has a roster of all who worked on the NBS fuzes.

[75] Hinman, p. 9. Essentially the same account of NBS fuze research as in Hinman appears in Joseph C. Boyce, ed., New Weapons for Air Warfare (OSRD, Science in World War II, Boston: Little, Brown, 1947), pp. 176–224.

A variety of principles were available for obtaining proximity detonation against a target, including photoelectric and reaction oscillator types under British investigation, a beating oscillator arrangement proposed by the Department of Terrestrial Magnetism, a pressure type based on the radio altimeter, and one on acoustic principles. The most promising for the nonrotating fuze, however, proved to be that utilizing the Doppler effect of reflected radio waves. Hinman and Diamond devised a diode detector arrangement that acted when the amplitude of the reflected signals exceeded a predetermined value, and with that the section began its experiments.[76]

Tests of the first series of crude box models using the radio principle were made between January and April 1941. Despite the fact that only a third of the cumbersome models functioned properly, they proved that a radio proximity fuze was practicable. Turning it into an operational service item was to take almost 2 more years.

Much effort was expended in the early months on the electronic circuits activating the fuze and then on its mechanical switches and safety mechanisms, since a serviceable fuze had to be so safe that anyone could handle and even abuse it without danger.[77] While the circuits and mechanisms proved out on the early models tested at low altitudes, dropping the box fuzes from 10,000 feet and higher produced dismaying results. The higher velocities in the drop set up vibrations that the radio tubes and other components could not withstand.

In the next series of models, instead of the original shock mounting, all components were made so stiff and rugged and mounted so rigidly that they were capable of resisting the severest mechanical vibrations. Circuit elements were either immersed in wax or fixed to a frame and given a heavy protective wax coating. As for the electronic tubes, small hearing aid tubes offered the best solution to difficulties with the large and structurally weak commercial tubes that had been used. Raytheon, Hygrade Sylvania, General Electric and others, already at work on this problem for the shell fuze project, subsequently produced small, high quality, exceedingly rugged tubes for both the shell and bomb fuzes.

A new method of arming the fuze, to improve its exploding time, was introduced in February 1942. It consisted of a special type of circuit that provided a delay in the charging time for producing the current that set off the detonator. Another improvement eliminated use of the bomb body as the antenna of the radio fuze, by building two bars into the fuze itself, providing an antenna separate from the projectile.[78] In May 1942, at

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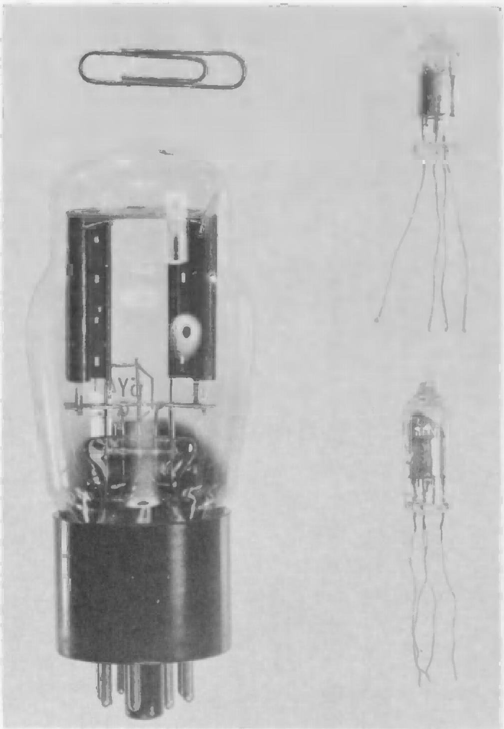
[76] Hinman, p. 9; RP1723, "Radio proximity fuze design" (Hinman and Brunetti, 1946).

[77] W. B. McLean and J. Rabinow were the chief designers of the switches and safety mechanisms (NBS War Research, p. 20).

[78] Hinman, pp. 11–13.



The miniaturization of the electron tube for use in the radio proximity fuze.

this stage in the basic design of the fuze, the Army set up a specific requirement. They wanted a VT fuze for their new 4.5-inch airborne rocket, then on the drawing boards, for use against the German Luftwaffe.

With fuze dimensions agreed upon, its design was completed in 2 days and construction of test models began. Complicated mechanical and plastic parts were fabricated by hand. Temporary switch and safety mechanisms had to be used. The batteries available were still too large for a service fuze but National Carbon and Burgess Battery were working on smaller ones.[79] The final design of the fuze head consisted essentially of a radio transmitter and receiver, a selective amplifier, an electronic switch, a detonator, an electric power supply, and arming and safety devices.[80] Since the 4.5-inch rocket was not ready, the fuze was set in a 3¼-inch substitute rocket. Test operations off the coast near Wilmington, N.C., started a month after receiving the requirement.

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[79] George W. Vinal's electrochemistry section in July 1941 produced a satisfactory low-temperature wet (perchloric acid) battery for use in the fuze, measuring 2¾ x 2½ inches, later replaced by a commercial dry battery (New Weapons for Air Warfare, p. 184).

[80] C. H. Page and A. V. Astin, "Survey of proximity fuze development," Am. J. Phys. 15, 95, 98 (1947).

Actually, tests of two fuzes were made at that time, the radio fuze developed by Diamond and Hinman's group and the photoelectric fuze by Taylor and Astin. Functionally, the photoelectric fuze was excellent. Equipped with a photoelectric cell and lens and triggered by its sensitivity to changes in light intensity, the fuze detonated its projectile when an object passed between a portion of the lens and the sky. Drawbacks of the fuze were its dependence upon light, making it useless at night, and its tendency to anticipate its target as sunlight moved into and out of the lens. With the help of the Bell Telephone Laboratories, methods for solving both difficulties were found, but the success of the radio fuze finally led to suspension of the photoelectric project in October 1943.[81]

For the tests in June 1942, construction of both radio and photoelectric fuzes for the Army rocket began on small-scale production lines at the Bureau and at Westinghouse. More than a thousand of the two fuzes were made in the Bureau's model shops, "bugs" were ironed out at the proving ground, and late that year, as complete specifications for the fuzes went to industry, full production began. Under procurement for the Signal Corps by agreement with Army Ordnance, almost 400,000 of each type were turned out in 1943 and an additional 400,000 of the radio fuzes before the end of the war.[82]

While the radio fuze for the rocket was primarily designed for use against aircraft in its limited use overseas it functioned equally well from airplanes and from ground rocket launchers against troops and gun emplacements. Its most spectacular use was in multibarreled projects mounted on the General Sherman tank, the 60 VT-fuzed rockets, released in 6 seconds, completely smothering the target area with their concentration of projectile fragments.[83]

Well before the end of 1942 the fuze program had completely outgrown the laboratory in which it began overflowing into a number of temporary structures put up in the open area across Van Ness Street. Upon the assignment of additional fuze types and other ordnance projects to the group that December, the Bureau organized the sprawling units into the ordnance development division, under the direction of Harry Diamond, for better administration of the work.

A month later Army Ordnance renewed its original request for a radio fuze for bombs. The bomb fuze was not, as originally planned, to be used against enemy battleships—the *Bismarck, Scharnhorst, Prinz Eugen,*

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[81] Rinehart MS, pp. 111–112; A. V. Astin, ed., "Photoelectric Fuzes and Miscellaneous Projects," vol. 3, Summary Technical Report of Division 4, NDRC (Washington, D.C., 1946), p. 20.

[82] Hinman, pp. 15–17, 31; NBS War Research, p. 21; Baxter, pp. 239–240.

[83] Hinman, p. 17.

An NBS proximity fuze model shop where test models of the fuzes, as well as early production models, were made prior to full-scale production.

and other raiders of the German Fleet had either been sunk or immobilized—but for air-to-air use against enemy bomber formations. Attack planes with these proximity fuze bombs were to climb above enemy air armadas and release their sticks over the formation.

Work on the bomb fuze was well under way before it was realized that such targets had grown scarce, that the Allies, not the enemy, were now sending out bombers in flood formations. The requirement was changed to an air-to-ground bomb fuze, to effect airbursts over troops and other targets of opportunity. When this fuze later arrived overseas it was also fitted into fragmentation bombs. In napalm (gel gas) bombs, the fuze eliminated ground penetration, to which the standard napalm bomb was subject, doubling the area covered by the gel. In these various forms it was used with deadly effect by the 12th Air Force in Italy against both troops and materiel.[84]

Since a bomb is not subject to setback at release, that is, the shock of acceleration upon which the arming of the rocket fuze depends, a different arming mechanism became necessary. The difference in fuze space in the bomb also required some physical redesign. The greatest concern in the bomb fuze, however, was with the dry battery used as a power source. As had been learned with the rocket fuze, it deteriorated rapidly in storage, lasting about a year ordinarily and not more than a month or 2 under tropical conditions. At the subzero temperatures encountered in high-altitude runs, the dry battery wouldn't work at all. Another means for powering the fuze had to be found.[85]

The solution was found by eliminating the batteries and using the arming system of the conventional bomb fuze. In that fuze a small wind-driven vane spinning as the bomb falls actuates the arming mechanism only after a certain number of turns of the vane. By attaching a miniature generator to the vane, sufficient electric power could be obtained for the proximity fuze. The generator assured almost indefinite storage life, performed well over extreme temperature ranges, and increased the safety factor since the fuze could in no way detonate the bomb unless the vane was running at high speed.

The generator designed by Zenith Radio, measuring ¾ by 2⅝ inches and built to run at 50,000 r.p.m., went into mass production. With it went a rectifier assembly made by General Electric about half the size of a cigarette, to convert the alternating voltage of the generator to direct current for the fuze. Tests of the new bomb fuze began in May 1943, and by

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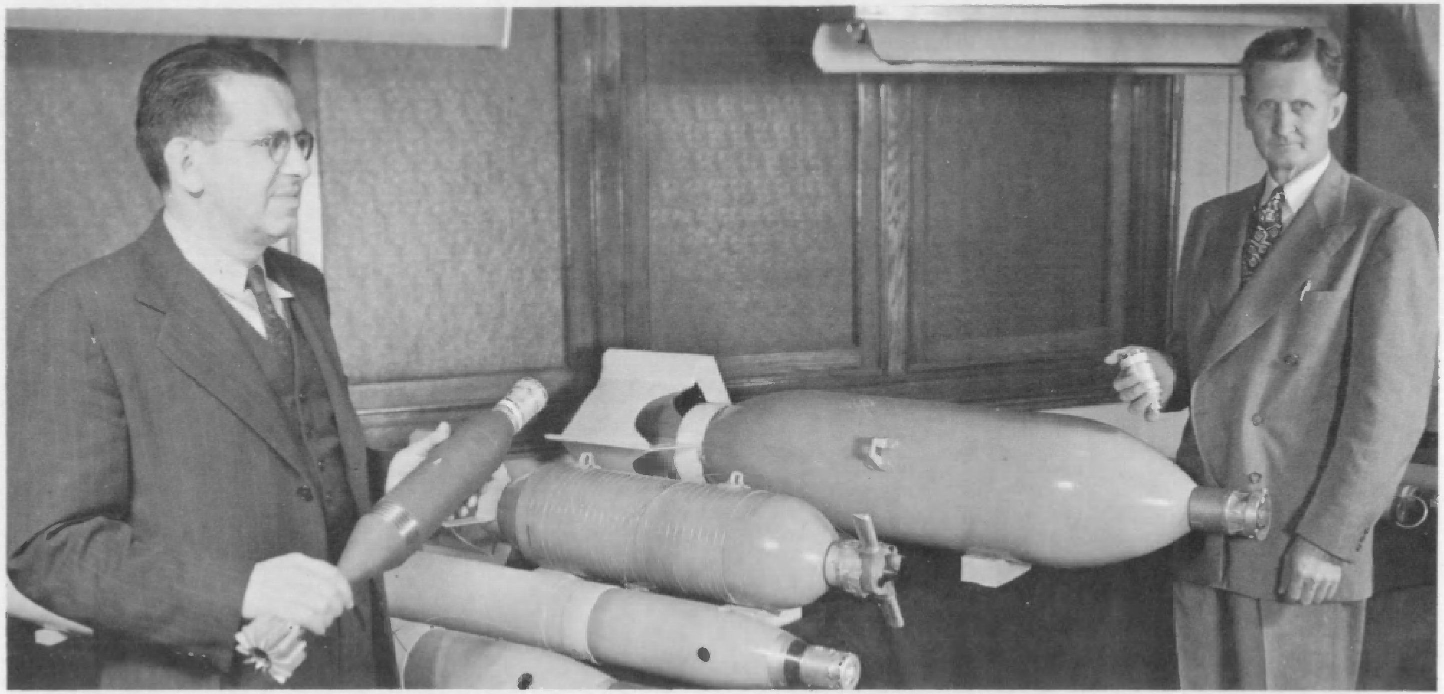
[84] British tests further disclosed that air-burst chemical bombs filled with a persistent agent such as mustard gas contaminated seven times the area covered by a surface burst. Hinman, pp. 33–34; Baxter, p. 241.

[85] Hinman, p. 18.



Five types of NBS radio proximity fuzes mounted on the weapons for which they were designed. Mr. Harry Diamond, at left, holds the 81-mm mortar shell with the mortar fuze. Dr. Alexander Ellett, Chief of Division 4, NDRC, holds the mortar fuze unmounted. Left to right on the table are a ring-type bomb fuze adapted for rockets, mounted here on a 5-inch high-velocity rocket; a later developed rocket fuze on the same rocket; a bar-type bomb fuze on a 260-pound fragmentation bomb; and a ring-type fuze on the 500-pound general purpose bomb.

November specifications for quantity production were ready. Army Ordnance called for the fuze on all its bombs between the 100- and 4,000-pound sizes. Approximately 1 million were made by Zenith, Emerson, Philco, and other radio manufacturing companies.[86]

Subsequent modifications made in the bomb fuze included a device designed at the Bureau by Jacob Rabinow to provide delay in arming and permit the fuzed bombs to drop safely through deep formations of bombers, and replacement of the vane mechanism with a miniature turbine, making the whole rotating system in the fuze more compact. Design of special components was initiated by Astin's group to insure optimum heights of burst, and finally a new generator appeared, measuring a mere 1⅛ by 1⅜ inches,[87]

As the sophisticated generator-powered bomb fuze went into production, the Navy through OSRD asked that it be adapted to their 5-inch aircraft rocket. The major modification consisted in changing the arming system from its vane gear back to the use of the acceleration provided by the firing of the rocket. Production of both air-to-ground and air-to-air versions began in December 1944, and both the Army and Navy used them in considerable numbers in the last months of the war.[88]

A late adjunct to employment of the proximity fuze bomb was a special bomb director mechanism, which together with toss bombing, insured bringing the missile close enough to its target for maximum effect. The toss-bombing principle and basic design of the mechanism, the acceleration integrater bomb release, was first suggested by Col. Harold S. Morton of Army Ordnance in January 1943 and developed under Alexander Ellett at the Bureau.[89]

The object of toss bombing is to compensate for the gravity drop of the missile in flight. Instead of depending on an educated guess about the point of bomb release, as fighter pilots did in attacking bomber formations or in dive bombing, the bomb director automatically computed the release point as the pilot commenced pulling out of his dive. The resulting trajectory of the bomb tossed it toward its target, allowing the pilot more time to take evasive action against ground or ship fire.

Some 500 bomb director sets were produced for the Army and Navy toward the end of the war, although only a few more than a hundred, fitted

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[86] Hinman, pp. 20, 31; Baxter, pp. 239, 241.

[87] Hinman, pp. 21–23; NBS War Research, p. 23.

[88] Hinman, p. 24.

[89] Letter, Acting Assistant Chief of Air Staff-4 to Col. H. S. Morton, Office of Chief of Ordnance, Nov. 8, 1945, and attached correspondence (copy in NBS Historical File); Rinehart MS, p. 158.

in the P-47 fighter plane in the European theater, saw service.[90] They also directed the bombs dropped on Hiroshima and Nagasaki.

The progressive reduction in size of the nonrotating radio fuze was eagerly observed by Army Ordnance, since they wanted it for their trench mortars. The fuzes in production, for all their miniaturization, still weren't small enough when the request came to the Bureau in the late spring of 1944. Besides the necessity of designing a fuze only one-third the size of those in the bomb and rocket, while retaining all their functions, the fuze for the Army's 81-mm mortar shell had to be capable of withstanding a firing shock of 10,000 times the force of gravity or 10 times that of the rocket fuze.

The extreme requirements in size and ruggedness were largely met by what was called a "radical innovation in electric construction" when the subcontractor, Globe-Union, Inc., found a way to produce a considerable part of the electric circuit of the fuze by painting conducting material onto ceramic plates and blocks.[90a] Production of three models of mortar fuzes with these new "so-called printed circuits" started a month after the surrender of Germany. They were initially turned out at the rate of 100,000 a month. In the expectation that the war in the Pacific would last until mid-1946 or early 1947, the rate had just been tripled when the war ended.[91]

The pressure to complete development and hasten production of fuzes both at the Bureau and in industry increased as preparations for the Normandy invasion began. Large quantities of bombs and rockets with the proximity fuze were assembled for use in the preinvasion air assault to soften up the beachhead. Teams headed by OSRD and Bureau members went to England to indoctrinate the U.S. Air Force in the maintenance and use of the fuzes. Then, shortly before D-day, the Air Force announced its decision not to use the fuze. In view of Allied air superiority, it was felt that enemy recovery of one of the fuzes would make the weapon more advantageous to them than to us. The proximity fuze for shells had been used by fighter planes in the Pacific since early 1943, but their use had occurred only over water where they were not recoverable. In Normandy, the fuze

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[90] Astin, ed., "Bomb, Rocket, and Torpedo Tossing," vol. 2, Summary Technical Report of Division 4, NDRC (Washington, D.C., 1946); Astin, ed., "Photoelectric Fuzes and Miscellaneous Projects," pp. 8-10.

[90a] Although the metalizing art was believed well known, Globe-Union rightly considered its printed circuit technique a trade secret, with great potentialities for the future, making possible economic mass production, saving space and weight, and increasing the reliability of electrical equipment. See Astin, ed., "Radio Proximity Fuzes for Fin-stabilized Missiles," vol. 1, Summary Technical Report of Division 4, NDRC (Washington, D.C., 1946), pp. 241-242, 248, 253-256; C. Brunetti and A. S. Khouri, "Printed electronic circuits," Electronics, April 1946, p. 104.

[91] Hinman, pp. 26-27; Baxter, p. 241; Rinehart MS, p. 182.

might be retrieved from the beach or beachhead. The same negative decision withheld use of the director mechanism for toss bombing.

So great were precautions to keep the proximity fuze out of enemy hands that it was not officially released for general use in the theaters until December 1944, 6 months after D-day. Even then its use was forbidden where enemy observers might identify the nature of the fuze. Among added precautions, the fuzes in rockets for use against aircraft were designed to destroy themselves before striking the ground in case of a miss, and bombs and rockets for air-to-ground strikes had an auxiliary contact fuze that functioned on impact in case of failure of the VT fuze. The single exception to the early restriction was use of the shell fuze in the British defense against the German V–1 robot bomb in the summer of 1944.

Following instruction courses given at the Bureau and at Aberdeen Proving Ground to Navy and Air Force teams, the first major combat use of the bomb fuze, by the 7th Air Force, occurred during the preinvasion bombardment of Iwo Jima in February 1945. In Europe both bomb and rocket fuzes, the latter in the new 4.5-inch rocket carried by fighter planes, were first used against German flak batteries and other ground targets in April.[92]

In 1944, as large-scale production was reached, over 8 million radio proximity fuzes were made, almost a quarter of them bomb, rocket, and mortar fuzes.[93] By then fuze plants were monopolizing 25 percent of the total facilities of the electronic industry and 75 percent of all molding plastics firms. And even more sophisticated fuzes were on the way. As production slackened with the end of the war, research was resumed in a search for better components and more versatile fuzes.[94]

A GUIDED MISSILE CALLED THE BAT

The Bureau borrowed on the wartime radar research carried out elsewhere for its construction of the "Bat," the first fully automatic guided missile ever used successfully in combat.

The guided missile program began late in 1940 when NDRC initiated research on a new weapon it believed might be useful to the services, a

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[92] Hinman, pp. 36–40; Baxter, pp. 240–241, 234–235.

[93] Of the 8.3 million fuzes produced, 61 percent went to the U.S. Army, 26.7 percent to the U.S. Navy, and the remaining 12.3 percent to the British armed forces (Baxter, p. 236 n.). It has been estimated that of the fewer than 2 million NBS fuzes made, probably no more than 20,000, primarily bomb fuzes, were used in the European and Pacific theaters (Astin, ed., "Bomb, Rocket, and Torpedo Tossing," p. 8).

[94] Baxter, p. 242; Rinehart MS, p. 260.

winged bomb which would automatically seek out its target and guide itself to hit the target. NDRC was proved right, but its missile was still a year away when in August 1943 German planes, out of range of antiaircraft fire, began to sink Allied shipping in the Bay of Biscay by means of radio-controlled bombs fitted with glider wings.[95]

The aerodynamic characteristics of the prototype weapon that was designed and constructed under RCA contract in 1940–41 presented a number of stubborn difficulties. Early in 1942 NDRC asked the Bureau for help by taking over the aerodynamic and servomechanism (control) development of the weapon. Hugh L. Dryden, chief of the mechanics and sound division of the Bureau and NDRC consultant, whose fundamental work on "Aerodynamics of aircraft bombs" was still basic in that field, was put in charge.[96]

Under the code name "Robin," several full-scale missiles of new design, intended to carry a standard 2,000-pound bomb, were constructed for the Bureau at the Vidal Research Corporation. Tests began in April 1942. The nose of the flying bomb vehicle contained a special RCA television transmitter with pickup tube for viewing the course of the bomb in its flight. A ground operator directed the bomb by manual remote radio control, watching a television receiver in front of him. The test results were not encouraging. Electrical interference and the noise and vibration of the glider seriously affected the television equipment and the servomechanism repeatedly failed under the varying conditions of flight.[97]

Among the observers of the flight tests were Navy Ordnance officers concerned at the time with a radar homing missile under development by the Naval Research Laboratory and the Radiation Laboratory at MIT. While one group at the Bureau continued work on the television-guided "Robin," another, convinced by the Navy of the possible superiority of radar in the Bureau's glider system, began modifying "Robin" to incorporate radar homing principles.

Two basic types of a radar missile were available. One envisioned a glider bomb with a radar receiver tuned to an enemy transmitter that enabled the bomb to home in on the transmitter. The other type contained both transmitter and receiver, in which the transmitter emitted short pulses of high intensity, guiding the missile by the returning echoes from the enemy object. As both types came under study in a new special projects section set up in Dryden's division at the Bureau, the section expanded to more than

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[95] Baxter, p. 194.

[96] The 210-page MS report of Feb. 28, 1927, is in NASA Library, File N–7569.

[97] NBS War Research, p. 30.

a hundred members, occupying the whole of the temporarily vacated hydraulics laboratory.[98]

The first radio-operated guided missile ready for testing was the "Pelican," a passive type using a radio receiver only, mounted in the nose of a 450-pound glider bomb. The plane carrying the Pelican illuminated the target with its radio transmitter and the bomb picked up the reflected waves and homed in on them. Foreseeing early use for the weapon, the Navy put the Pelican under highest priority and augmented the staff with a Navy Ordnance Experimental Unit at the Bureau and a Pelican Test Group at Lakehurst, N.J., where the flight tests were to be made.[99]

With receivers provided by Zenith and gliders by Vidal, final assembly was made at the Bureau. The first flight demonstrating homing control took place in December 1942. In the haste to construct test models and get them into production as their design proved satisfactory, minor difficulties with instrumentation were accepted which seriously flawed the production tests. As it turned out, only slight changes in the target selector circuits of the Pelican were necessary to overcome the repeated failures of the missile, but by then the greater promise shown in a concurrent project, the "Bat" missile, a 1,000-pound flying bomb, claimed the major Bureau effort.[100]

As bats emit short pulses of sound and guide themselves by the echo, so the Bat missile, sending out shortwave radiation, was directed by the radar echoes from the target. Unlike the Pelican, the sending and receiving radar set in the Bat made the weapon self-sufficient, since it illuminated its own target. Bell Telephone Laboratories and MIT scientists designed the radar robot pilot of the Bat, while groups under Hunter Boyd and Harold K. Skramstad at the Bureau worked out its aerodynamic and stabilization characteristics.[101]

Flight tests of the Bat, its 10-foot glider wing supporting a dummy bomb, started in May 1944. That autumn, in comparative tests between the Pelican and Bat against a ship hulk anchored 60 miles off shore, both performed well and were accepted. In one respect, as it turned out, the Pelican was somewhat the superior of the two, since its range of 20 miles exceeded

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[98] NBS War Research, p. 31.

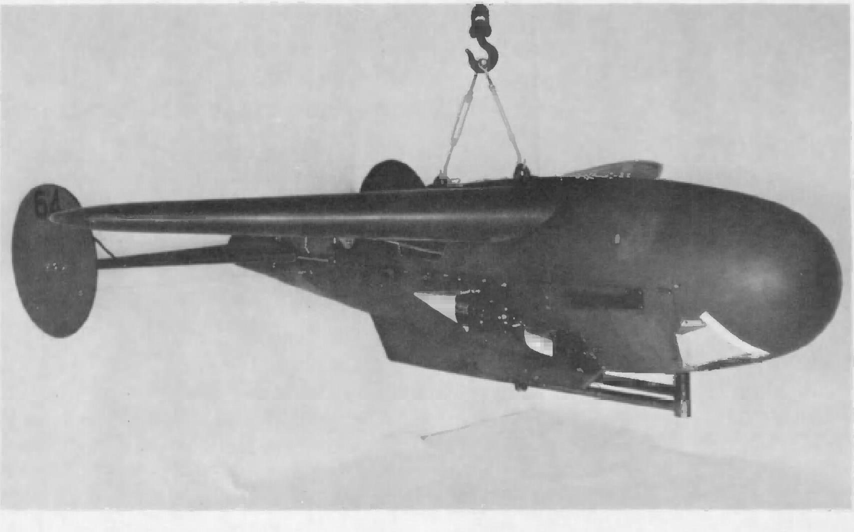
[99] Baxter (p. 195) describes the Pelican as originally an antisubmarine weapon, using a standard depth bomb and a scaled-down air frame steered by its radar receiver from a transmitter in the attacking plane. When the submarine threat receded, "the idea of a glide bomb which would follow a radar beam directly to the target was * * * too good to abandon," and research on the glide missile continued as a weapon against shipping.

[100] NBS War Research, p. 33.

[101] Ibid. A notable report on fundamentals was Dryden's "Some aspects of the design of homing aero-missiles," NBS Report to Division 5, NDRC, October 1945, and attached correspondence (NARG 227, OSRD, Division 5, Box 655).

The "Bat," borne by a Navy torpedo bomber, rides with folded tail fins until, upon release, they open into proper flight position.

The first fully automatic guided missile to be successfully used in combat, the Bat was designed for use against enemy shipping, and particularly against surfaced submarines. The Bat's outstanding features were its self-guidance after release, its long range, high accuracy, low angle of flight, and high pay load.



The "Pelican," developed with the cooperation of the Navy Bureau of Ordnance and the MIT Radiation Laboratory. Here it is rigged with instrumentation for flight tests, the 16 mm gunsight aiming point camera directly beneath the wing pointing at a panel of signal lamps indicating radar controls being applied, and the 16 mm camera, slightly lower and forward, pointing at the ground ahead of the glider.

that of the Bat. But the decision had been made and only the Bat went overseas. In the final months, land-based Navy patrol squadrons in the Pacific made effective use of it against Japanese naval and merchant shipping and against land targets in the forward areas.[102]

Complex and formidable as the Pelican and Bat seemed at the time, they were but pale prototypes of the missiles to come in the postwar years.

RADIO AND RADIO-WEATHER PREDICTING

An important weapon in subduing the German submarine menance was the high-frequency direction finder, called "Huff-Duff," a play on its initials, h–f–d–f. Its progenitor was the radio compass or direction finder designed by Frederick A. Kolster of the Bureau in 1915.[103]

When early in the war the Allies established the convoy system for the Atlantic crossing, the U-boats began stalking the convoys in wolf packs, using their wireless to direct the group operations. The wireless gave away their positions to British and American Huff-Duff stations and allowed radar-equipped planes from land bases or carriers to find them.

Errors in accuracy in existing Navy, Signal Corps, and commercial direction finders sometimes caused the search planes to miss the enemy packs. In April 1941, NDRC requested the Bureau to study the errors in high-frequency finders and determine techniques for measuring these errors. Out of the research came new techniques for assessing a variety of errors possible in the direction finders themselves, and correlation of these errors with the influence of atmospheric disturbances on the finders. The results were set out in two important papers prepared for NDRC, one by Diamond, Lyons, and Post on "High-frequency direction finder apparatus research by the NBS," the other by Kenneth Norton on "The polarization of downcoming ionospheric radio waves." The latter paper NDRC acclaimed as "a thorough development of the physics of ionosphere reflections [that] has become a classic on the subject," and much of the subsequent research on direction finders, both in NDRC and in Allied research centers, was based on the fundamental theories set down in these two reports.[104]

By June 1943 Huff-Duff, together with Asdic, radar, Loran, sonar, and voice and radio communication, had driven the wolf packs from the North

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[102] NBS War Research, p. 34; Boyce, New Weapons for Air Warfare, pp. 225–235.

[103] See ch. III, p. 142.

[104] See C. G. Suits, G. R. Harrison, and L. Jordan, eds., Applied Physics, Electronics, Optics, Metallury (OSRD, Science in World War II, Boston: Little, Brown, 1948), pp. 135–136, 140.

Atlantic.[105] The Huff-Duff investigation, however, was only a single aspect of a much more extensive project at the Bureau involving the ionosphere and its wide range of effects on radio communications of all kinds. Studies of these effects, as manifestations of radio-weather, had already led to techniques of predicting, with growing accuracy, their influence on communications.

For good reason, then, a month after Pearl Harbor a Bureau letter circular on radio-weather predictions was withdrawn from circulation and all further open publication on the subject ceased. Its data on radio distance ranges had become military secrets and remained so throughout the war.[106]

The influence of the ionized layers of the earth's upper atmosphere, the ionosphere, on radio wave propagation had been recognized ever since the independent experiments of Breit and Tuve and of Appleton in 1925 proved its existence.[107] Through the next decade Norton, Kirby, Gilliland, and Newbern Smith at the Bureau devised a number of techniques for extending the range of ionospheric measurements.[108] Because of the scarcity of ionospheric data and because few realized its importance, use of such data in radio communications before the war was relatively small. The military value of precise knowledge of the usability of various radio frequencies at specific times over specific transmission paths thus gave an enormous impetus to the compilation of sky data during the war.

From the point of view of the services, the extreme crowding of the radio-frequency spectrum made propagation data necessary for the best selection and allocation of available frequencies. Security considerations also dictated that the frequencies used be those least likely to be intercepted by the enemy. Design of new equipment, especially antennas, depended upon knowledge of radio propagation conditions. Finally, not only all radio aids for air navigation over the North Atlantic, but radio direction finding, radiotelephone, radar, telegraphy, and radioteletype required better knowledge of propagation ranges, accuracy, and receivable intensities.

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[105] Baxter, pp. 38, 45; NBS War Research, pp. 43–44. The Mathematical Tables Project of the Bureau, located in New York, did important work for the Navy on its Loran tables and other computations. Interview, Dr. Franz L. Alt, June 30, 1964.

[106] LC658 (1941). Excepted from classification were the standard frequencies and other broadcasting services provided by the Bureau (see LC591, 1940).

[107] For the work of Breit, Tuve, and Appleton, see RP632, "Studies of the ionosphere and their application to radio transmission" (Kirby, Berkner, and Stuart, 1934).

[108] RP597, "A continuous recorder of radio field intensities" (Norton and Reymer, 1933); RP752, "An analysis of continuous records of field intensities * * *" (Norton, Kirby, and Lester, 1934); RP1001, "Characteristics of the ionosphere * * *" (Gilliland, Kirby, Smith, et al., 1937); RP1167, "Application of graphs of maximum usable frequency * * *" (Smith, Kirby, and Gilliland, 1939).

An aircraft disaster in the European theater, attributed to failure of communications resulting from a magnetic storm, led the British and, soon after, the Australians to establish their propagation services in 1941, in order to furnish radio weather predictions to their Armed Forces.[109] A similar program had its inception in this country when NDRC asked the Bureau to prepare a textbook for the services on basic principles of radio skywave propagation. Assembled by a group under Newbern Smith in Dellinger's radio section, the Radio Transmission Handbook—Frequencies 1000 to 30,000 kc, appeared a year later, in January 1942. In addition to the principles, it gave such computational procedures as were then available, offered preliminary versions of prediction charts, and provided radio predictions for that winter. A supplement in June gave the summer predictions.

So valuable was the information in these handbooks to service radio communication systems that NDRC asked the Bureau to continue the work, and in the summer of 1942, by order of the U.S. Joint Chiefs of Staff, the Interservice Radio Propagation Laboratory (IRPL) was established at the Bureau. It was directed to centralize radio propagation data and furnish the resulting information to the services.[110]

The data were compounded of a number of variables of which little was known. First of all, long-range radio communication depends upon the ionosphere, which acts as an infinite series of tiny radio mirrors to reflect signals back to earth. Communication is imperiled, no matter how good the transmitting or receiving equipment, unless radio waves are propagated with sufficient strength to be receivable. That strength depends upon knowledge of the ever-changing characteristics of the ionosphere, which vary with latitude and longitude, geomagnetic latitude, layer height, ionization density, energy absorption, and radio noise. The latter, radio noise, is both geophysical, caused principally by thunderstorms, and extraterrestrial (stellar and solar), resulting from meteor activity and solar storms.[111]

To predict useful frequencies over skywave paths anywhere in the world, the Bureau had first to obtain adequate ionospheric data on a worldwide basis. With the data, it had to establish methods for calculating maximum usable frequencies over long paths, methods for calculating skywave

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[109] Unavoidable because it results from the event, yet similar as a phenomenon, is the total blackout of radio communications experienced by the astronauts in their space flights while reentering the atmosphere. The heat of the falling capsule during reentry ionizes the air around it, sealing off both incoming and outgoing radio signals and stopping registration of the instruments tracking the capsules.

[110] Suits, Harrison, and Jordan, Applied Physics, Electronics, Optics, Metallurgy, pp. 148–9. For the wartime financing of IRPL, first by the Bureau, NDRC, Army, and Navy, and after 1943 wholly by the Army and Navy, see memo, Deputy Secretary, Joint Communications Board, JCS, for Director, NBS, May 24, 1945 (NBS Blue Folder Box 24).

[111] Dellinger, "The ionosphere," Sci. Mo. 65, 115 (1947).

field intensity, determine minimum required field intensities, and methods for forecasting ionospheric storms.

At the time, ionospheric observations were available to IRPL only from the Bureau laboratory in Maryland, two observatories in Australia, and one in New Zealand.[112] Before the end of the war, through the cooperation of the Carnegie Institution of Washington, the U.S. Army and Navy, the Canadian Navy and Air Force, the new British and Australian propagation services, the British Admiralty, the National Physical Laboratory, the British Broadcasting Corp., and the U.S.S.R., 44 stations were regularly reporting ionospheric observations by cable and radio, in cipher, to IRPL.

As a first step, the Bureau evolved a technique for predicting ionosphere characteristics on a worldwide basis, using standard statistical methods and recording the data on comprehensive charts published for the services each month. Next, a simple rapid method was devised for obtaining the maximum usable frequency (m.u.f.) over sky paths in any part of the world for distances up to 2,500 miles. The method made possible preparation of world charts giving predictions of m.u.f. 3 months in advance. The preparation and distribution of these charts, which began in April 1942, was the most important achievement of the Bureau in the field of skywave propagation.[113]

The urgent need to know distance ranges and lowest useful high frequency (l.u.h.f.) necessitated many more calculations of skywave field intensities than were currently available. The Bureau's intensity-recording program, begun early in the previous decade, was expanded by installing recorders at new ionospheric stations set up in the services and elsewhere on the North American continent. Commercial radio companies supplemented these records with their observed worldwide radio traffic log sheets. With the data on skywave field intensity, knowledge of the minimum field densities necessary to overcome atmospheric radio noise was also required. A study began of thunderstorms, the common source of this noise, whose principal generating centers are in the East Indies, Central and South America, and Africa, with secondary centers in the tropical oceans.

A final major problem of IRPL was forecasting ionospheric storms, the great magnetic storms, invisible but of vast energy, triggered by solar flares and eruptions that often blanket the earth and for periods of

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[112] The Bureau's ionosphere recording equipment and field intensity recorders were located at its field station at Meadows, Md., until 1942 when the Air Force took over the site for Andrews Air Base. The Bureau found another meadowland, an area of 450 acres, at Sterling, Va., near Chantilly, 23 miles northwest of the Bureau. That too was lost when in 1954 it became the site of the Dulles International Airport. By then other field stations of the Bureau, including those at Boulder, Colo., were providing adequate coverage.

[113] NBS War Research, p. 36.

a few hours to several days disrupt all sorts of electrical and electronic equipment.[114] In a magnetic storm, the ionosphere tends to absorb signals instead of reflecting them, often temporarily knocking out long-distance telephone lines and scrambling telegraph transmission and the transatlantic radio circuits upon which overseas flights depend. The military importance of the North Atlantic flight path, which reaches into the auroral zone or zone of maximum disturbance, thus made it imperative to know when communications were likely to be interrupted.

Studies of the behavior of radio direction finder bearings and other ionospheric and cosmic data over the North Atlantic path gathered by monitoring stations in Europe showed that it was possible to predict the advent of a radio disturbance to shortwave communications and issue warnings a few hours to half a day or more in advance. Using these data the Bureau's short-time warning service was inaugurated in 1943.[115]

By the autumn of 1943 adequate solutions to the major difficulties in radio weather predicting had been found and the result was the IRPL Radio Propagation Handbook that appeared in November as an IRPL issue, an Army training manual, and a Navy publication. It described the behavior of the ionosphere and the theory behind maximum and lowest useful frequencies. It discussed the preparation of prediction charts and the techniques for determination of useful frequencies over any path at any time, to the extent that they had become known.[116] The new world of radio explored by the handbook bore only remote resemblance to that described in the handbooks on elementary electricity, radio circuits, and radio measurements that supplied the needs of World War I.

From 1925 to the end of World War II, the radio section of the Bureau was almost wholly engaged in studies of the ionosphere and in radio engineering projects, including its blind landing system, the radiosonde, the proximity fuze, and guided missiles. With a single important exception, radio standards work went into somewhat of an eclipse in that period. The exception was in new precision frequency measurements.

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[114] For an interesting account of magnetic storms, particularly the great storms of March 1940 and February 1958, see John Brooks, "The subtle storm," The New Yorker, Feb. 7, 1959.

[115] Dellinger and N. Smith, "Developments in radio sky-wave propagation research and applications during the war," Proc. IRE, 36, 258 (1948).

[116] Two months after the IRPL handbook came out, the Bureau began a 2-week training course in the principles of radio weather predicting and methods of problem solution for Army Air Force, Signal Corps, and Navy officers and enlisted men. Some after training went to oversea communications groups and took charge of assignment of radio operating frequencies in the field. Others were sent to training units to organize additional radio weather predicting courses.

As a requirement of the radio wave propagation studies, a group under Harold Lyons undertook in 1944 to establish national primary standards of microwave radio frequencies. Assisted by the military, OSRD, and industrial laboratories, the Bureau set up frequency standards with an accuracy of 1 part in 10 million covering the microwave range continuously up to 30,000 megacycles. All frequencies in the study were derived from a special group of quartz crystal oscillators which constituted the national primary standard of frequency.[117]

At this point some note is appropriate about the multimillion dollar stockpile program in quartz crystals that occupied over a hundred members of the Bureau during the war. It was known that tremendous numbers of quartz crystal oscillator plates would be required by the armed services in their tank, plane, and field radio equipment, in naval communication apparatus, in radar and other detection equipment, and in many electronic precision instruments. In radio the plates not only serve to tune both transmitters and receivers to a desired frequency and to hold the frequency of transmitters within very narrow limits, but also to permit quick changes from one frequency to another merely by changing the crystal in the circuit.

The quartz crystal from which the plates are cut is almost worldwide in distribution but except in Brazil is of inferior quality and available only in insignificant amounts. Just prior to the war, Great Britain, Germany, and Japan, in a scramble to stockpile the crystals, were taking 94 percent of Brazilian output. A mere 4 percent satisfied U.S. requirements.

When in early 1940 quartz crystal was declared critical, it was established that the United States must stockpile at least 100,000 pounds of usable quartz. In March the Procurement Division of the Treasury asked the Bureau to help formulate specifications for crystals of radio grade and to test those to be purchased for the stockpile. Through the first half of 1941 the total amount of raw crystals received came to less than 50,000 pounds.

With our entrance into the war, quartz crystal, still critical, became a strategic material as well, that had to be denied to the enemy at any cost.[118] The Metals Reserve Company of the Reconstruction Finance Corporation, taking over from the Procurement Division, at once contracted for the entire

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[117] CRPL report, "Radio standards," n.d., p. 8 (NBS Historical File); NBS War Research, p. 39.

[118] Other materials also subject to preemptive or preclusive buying, regardless of cost, by the U.S. Commercial Co. set up under the RFC in March 1942, included wolfram (the source of tungsten used to harden steel), rabbit furs, wool and blankets from Spain, Turkish sausage casings, and all of Portugal's sardines. See Jesse H. Jones, Fifty Billion Dollars: My Thirteen Years with the RFC, 1932–1945 (New York: Macmillan, 1951), pp. 387 ff.

Quartz crystal inspection and testing laboratory, through which more than 6 million pounds of the crystals passed. These are 1-pound raw pieces, from which the small oscillator plates needed in radio and other electronic equipment will be cut.

output of Brazil. So important was it considered to sequester the crystal that almost all that was brought out of Brazil came by air freight, to avoid the possibility of interception by enemy shipping.[119]

As Brazil expanded her mining of quartz to satisfy the insatiable demand for the strategic material, the quality fell off.[120] To handle the volume coming in and salvage and test usable crystal from the raw material, the inspection group under Frederick J. Bates of the polarimetry section at the Bureau rose from the original 3 members assigned to the project to 63 trained inspectors and 13 laborers working in two shifts. By July 1942, with close to 100,000 pounds coming in each month (a year later, five times that amount), three shifts were necessary. The staff finally totaled 166, housed in three temporary structures along Connecticut Avenue, simply to grade and test the incoming quartz.

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[119] Jones, pp. 448, 575–576. Worldwide exploration in search of the crystal during the war brought the Bureau 73 shipments from 16 foreign countries, but mainly from Mexico, Guatamala, and Colombia. Exploration at home resulted in over 300 shipments from 25 States and Alaska. None of these sources produced significant amounts. NBS War Research, p. 50.

[120] The size of the mined crystal ranged between less than a pound up to 290 pounds and the value between $1 and $30 per pound, depending upon quality.

In 1943 a quartz research laboratory was added to the complex, where technicians under Francis P. Phelps undertook X-ray measurement studies of the crystals, standardization of quartz plates, and fabrication of experimental plates from mother crystal.[121] Before the war, optical perfection of the crystal had been used as the criterion of electrical performance. The quartz laboratory showed that this was not necessary, and as a result new specifications established for the agencies using the crystal made possible regrading of more than 2 million pounds previously rejected by the Bureau.

At the peak of production, 111 firms in this country were drawing on the stockpile at the Bureau to manufacture almost 2 million oscillators each month for the radio equipment of our Armed Forces, for commercial use, and for shipment to our Allies. Shortly before the project closed at the end of April 1946, the Bureau reported it had classified and graded over 6 million pounds of crystalline quartz, or 60 times the original stockpile requirement.[122]

RESEARCH IN CRITICAL MATERIALS

Quartz crystal found a place on every list of critical and strategic materials drawn up on the eve of war. As in 1917, the course of the war in Europe had made our entrance certain before this country began to take stock of its raw material resources and requirements. When it did, it found disquieting lacks not only in quartz crystal but in antimony, chromium, cocoanut char, ferro-grade manganese, magnesium, manila fiber, mercury, mica, quinine, silk, tin, and tungsten. Badly needed too were aluminum, asbestos, cork, graphite, hides, iodine, kapok, optical glass, toluol, vanadium, and wool. It was also evident that enormous quantities of steel and petroleum must be produced, and almost unlimited amounts of copper. But leading all the lists, and most frightening, was the rubber shortage, upon which the wheels of war rolled.[123]

As once before, the Bureau was to make important contributions to research in many of these materials, to the search for substitutes, and to better utilization of available supplies. At the outset, in the emergency, it had an active part in many phases of the establishment of the new synthetic

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[121] NBS War Research, pp. 45–46.

[122] NBS War Research, pp. 49–50; letter, EUC to Executive Director, Office of Metals Reserve, Jan. 18, 1946 (NBS Blue Folder Box 71).

NOTE.—A memorandum of Apr. 1, 1942, in the building data files of the NBS plant division discloses that at that early stage of the program the value of the quartz stored at the Bureau was $5 million. Assuming a medial value of $10 per pound, the total value of all tested and stockpiled quartz must have come close to $60 million.

[123] Nelson, Arsenal of Democracy, pp. 9–10, 38.

rubber industry—generally acknowledged the outstanding national accomplishment of World War II.

Until the war, synthetic rubber in this country remained a laboratory curiosity.[124] No one, not even Dupont with its experimental Neoprene, believed large-scale production feasible. New technical research and stark necessity were to make it so.

Following a visit by Lawrence A. Wood and Norman P. Bekkedahl of the rubber section to the major German synthetic rubber research laboratory at Leverkusen in 1938, the Bureau prepared a circular based on their observations and on the published literature available.[125] Widely called for after the defeat of France, the circular went through further reprintings as the rubber-producing areas of the British, Dutch, and French in the South Pacific fell before the Japanese advance.

In February 1942 leaders in the petroleum and chemical industries were brought together. They agreed to pool their patents and trade secrets and undertake operation of the synthetic rubber plants that the Government proposed to finance. The initial goal of the plants was set at 400,000 tons a year, a deliberately optimistic figure although it was far below the 900,000 tons of natural rubber consumed in 1941, most of it to make the automobile tires on which the American public had come to depend for locomotion.[126]

Until the war, the raw materials of experimental synthetic rubbers came largely from organic chemicals, manufactured gas, and byproducts of the coking industry. Militating against these rubbers was the production of their components. Neoprene, for example, though it had excellent resistance to oil, required huge quantities of chlorine, and chlorine was in chronic short supply. What made the new industry possible were the synthetics derived from petroleum and, to a lesser degree, the distilling industry's grain alcohols.[127] These synthetics were butyl rubber, well adapted for gas masks, barrage balloons, and inner tubes, and Buna N and Buna S, tougher rubbers suitable for tire casings. After considerable experimenting and testing, ma-

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[124] For early Bureau interest in the possibilities of synthetic rubber, see letter, GKB to J. M. Morris, MIT, Feb. 4, 1926 (NBS Box 173, ISR).

[125] C427, "Synthetic rubbers: a review of their composition, properties, and uses" (Wood, 1940). Although synthetic rubber cost three to four times as much as natural rubber, by 1940 Germany and Russia, seeking self-sufficiency, had gone over wholly to the synthetic. Experimental in this country but in most cases in production abroad (under other names) were Dupont's Neoprene, a chloroprene polymer; the German Buna rubbers, from butadiene derived from the cracking of petroleum; Thiokol, an organic polysulphide made by the Thiokol Corp. in this country; Vistanex, Standard Oil's isobutane polymer, from petroleum; and Koroseal, Goodrich's vinyl chloride polymer.

[126] Jones, Fifty Billion Dollars, pp. 399, 406.

[127] Butadiene from alcohol cost 40 cents per pound in 1945, from petroleum 10–14 cents. Hearings * * * 1949 (Jan 20, 1948), p. 546.

jor production finally centered on Buna S, the butadiene-styrene composition known as GR–S (Government Rubber—Styrene).[128]

Apart from its studies in 1942 of the polysulphide Thiokol as an interim synthetic for retreading tires, the Bureau rubber section was initially kept busy testing new processes for making rubber that were submitted by public spirited citizens. Rubbers were brought in that had been distilled from the oil of vegetable refuse, from gelatins, glycerine, and tannic acid, and even concocted from rubber itself. None could be wholly ignored. There was always a chance that a new composition or process might be found. But none was, and Donald Nelson, director of the War Production Board, paid a mixed tribute when he said of the hopeful that each with his product was sent "to the Bureau of Standards, on whose hard-working scientists we inflicted all these 'inventors.' "[129]

Bureau participation in the fledgling industry expanded early in 1943 when it was directed to assist the Rubber Research Co. in standardizing the quality of the synthetic rubbers coming into production. More than 50 reports described the test and analytic procedures developed by the Bureau, including methods for determining the styrene content of the GR–S copolymer and the purity of its styrene, butadiene, and other hydrocarbon components, and procedures for determining density, specific heats, and thermodynamic values of GR–S and of the polymerization of styrene.

The studies led to the preparation of a series of standard control polymers making uniform production possible. The controls, specifications, and rapid routine methods of analysis established for the first of the synthetic rubber plants were proved out as each of the other plants came into production. By late 1944, 19 Government-owned plants across the Nation were making synthetic rubber meeting identical specifications, resulting in a product more nearly uniform in quality than natural rubber.[130] The new billion-dollar industry turned out over 700,000 tons of rubber that year, and as the war ended was operating at a rate in excess of a million tons annually. By then 87 percent of the rubber consumed in the United States was synthetic and the industry was producing one-third again as much rubber as the country had actually used before the war.[131]

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[128] Buna S was essentially a compound of butadiene, from grain alcohol or from petroleum products, and styrene, from ethyl benzene derived from petroleum and coal tar.

[129] Nelson, p. 300; NBS War Research, pp. 117–118.

[130] Frank Freidel, America in the 20th Century (New York: Knopf, 1960), p. 399; Hearings * * * 1946 (Feb. 2, 1945), pp. 261, 270–273; NBS War Research, pp. 115–116.

Feeding the 19 rubber-making plants were 15 others producing butadiene, 5 making styrene, and 9 producing other necessary chemicals (Jones, p. 415).

[131] Jones, pp. 401, 414. Only the Federal Government could afford the construction of whole industries such as aircraft manufacture, nonferrous metals (magnesium and

Dr. Briggs was given a bad moment or two over an incident during the rubber crisis. Early in 1945, the very active Senate Special Committee Investigating the National Defense Program (the Truman Committee) called on him to explain how a study he had made in the bouncing characteristics of golf balls and baseballs could possibly contribute to the war effort. The Committee pointed to a paper he had just published, wonderfully entitled: "Methods for measuring the coefficient of restitution and the spin of a ball." [132]

Dr. Briggs explained and the committee subsided. Prodded to conserve rubber, even in miniscule amounts, the Services of Supply had asked the Bureau about a substitute material being used in the baseballs it was supplying recreation centers at training camps. Extending an investigation he had made of golf balls in an idle hour before the war, Dr. Briggs took on the SOS request himself. The work, he reported to the committee, had been done by a high school boy. He had merely made the analyses, with assistance from Dr. Dryden and Dr. Buckingham on the theoretical considerations.

In baseballs with balata cork centers (made official in the major leagues in 1943), the coefficient of restitution or liveliness of the ball, Dr. Briggs found, was measurably reduced over that of the prewar rubber-cushioned cork center (official in 1938). The coefficient was still lower in baseballs with reclaimed rubber centers. "A hard-hit fly ball with a 1943 center," Dr. Briggs reported, "might be expected to fall about 30 feet shorter than the prewar ball hit under the same conditions." [133] It was an important finding, contributing to the peace of mind not only of the professionals but of the sluggers in the training camps.

The rubber shortage was not solved without considerable anguish to the American motorist, who was first persuaded to turn in any extra tires of natural rubber he might have above the five for his car, and was then severely rationed on gas, to save the rubber he had left. It was a long wait before he got his first synthetic tire.

As the first of the synthetics came out of the molds, the Department of Commerce requested the Bureau to road test them, along with tires made wholly of reclaimed rubber, for possible military service as well as civilian use. The early synthetic tires of Buna S proved satisfactory in all respects but resiliance and adhesiveness, and they ran hot, especially with heavy

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aluminum), machine tools, synthetic rubber, and shipping required by the war. The RFC financed some 920 new defense plants for the War and Navy Departments at a cost of $6 billion (Jones, pp. 316, 328, 342, 345).

[132] RP1624 (1945).

[133] Letter, James M. Meade, chairman, Special Committee, to LBJ, Mar. 30, 1945 (NBS Box 504, IN).

loads or increasing speeds.[134] Nevetheless, the public had to get along with them since no natural rubber could be spared. Although later synthetic tires were far more satisfactory, tire production was restricted, for much of the new rubber was going into other products. Among materials made of the new rubber and tested by the Bureau for military or domestic use were rubber parts for landmines, cords for barrage balloons, pontoon fabrics, crash pads for tanks, gaskets, soles and heels on shoes, jar rings for home canning, flexible hose, and wire and cable insulation.[135]

While the Bureau, to be sure, could do nothing about the sharp restrictions placed on the use of motor vehicles or the national speed limit, set at 35 miles per hour, it did hurry out a letter circular on how to prepare one's car for dead storage.[136] And it saved many civilian motorists, as well as the military, a devastating headache that threatened when the standard antifreeze compounds, ethylene glycol and ethyl alcohol, were declared critical. The market was soon flooded with substitute compounds with salt or petroleum bases. The War Production Board at once stopped their manufacture or sale when the Bureau demonstrated the dangerously corrosive action of salt compounds, even with inhibitors, and the rapid disintegration of radiator hose caused by even the most highly purified petroleum compound.[137]

Second only to the shortage of rubber was that of steel and steel plate, for the building of ships, war plants, and expansion of steel plants themselves. To feed the blast furnaces, branch rail lines and spurs and abandoned trolley lines all over the country were torn up and buildings and bridges that had fallen into disuse were demolished for their metal.

Equally critical were some of the alloying agents used in steel production, particularly in the making of armorplate and projectiles. The extensive review that was made of specifications of Government buying agencies was not only important but imperative, and the work of the metallurgical experts at the Bureau and in industry to produce "lean-alloy" steels, using less tungsten, less molybdenum, less vanadium, while retaining the essential

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[134] RP1574, "Measuring the rate of wear of tire treads" (Roth and Holt, 1944).

[135] Hearings * * * 1944 (Feb. 26, 1943), p. 82; M185, "Rubber research and technology at the NBS" (Wood, 1947); RP1554, "Buna-S-Gilsonite for insulation of communication cables" (Selker, Scott, McPherson, 1943); NBS War Research, p. 117.

[136] LC694 (March 1942).

[137] NBS War Research, p. 180; Hearings * * * 1944, p. 81. A number of gasoline additives also came on the market with the usual claims of greatly increased mileage and improved power. Not one except an additive containing iron pentacarbonyl was found useful in the slightest, and while the pentacarbonyl acted like tetraethyl lead to suppress knock, it greatly increased engine wear (Hearings * * * 1944, p. 80).

properties of the steel, became one of the most important jobs done in 1942 and 1943.[138] A significant contribution was the finding made by a Bureau group headed by Thomas G. Digges under NDRC contract, that boron, available in unlimited quantity, might be substituted for a part of the chrome ores commonly used in making hard steel.[139]

The anticipated shortage of chromium-nickel stainless steel launched an investigation under W. H. Mutchler for a substitute for the firewalls between the engine and cockpit of planes. Low-carbon sheet steel with either a thin stainless-steel coating or aluminum coating was found most satisfactory, withstanding high-temperature flames for periods up to 15 minutes without failing. Another acceptable substitute was steel coated with a special heat-resistant vitreous enamel, in place of stainless steel, in the exhaust manifolds on airplane engines and landing craft.[140]

Bureau specialists in metallic erosion and corrosion, in protective coatings, and electroplating were on constant call by industry and the services. Over 5,000 industrial or service items were submitted for solution of coating problems or determination of the effectiveness of metallic or organic (i.e., emulsion or wax) coatings applied against high humidity or salt water. They included food cans, almost all munitions, helmet parts, lifeboat, aircraft navigation, and field equipment, electrical instruments, proximity fuzes, and various firing mechanisms. Even so small an item as the match came to the Bureau for a coating. With the protection devised for their use in the tropics, the matches withstood 5 days' exposure to 95 percent relative humidity or, equally well, immersion in water for 5 hours.[141]

Under William Blum, the electrodeposition section saved tons of precious copper and nickel in the manufacture of printing plates for the Government Printing Office when it showed that these metals could be replaced by iron deposited from suitable plating baths. The section also made improvements in the properties of chromium plating of gun barrels that in the case of machine guns increased the life of the barrel by 30 times over steel barrels. Substitution of steel for brass in cartridge cases, it was found, required coating the cases with electroplated zinc. A baked phenolic varnish also worked well. Other items made serviceable by electroplating with

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[138] Nelson, p. 351.

[139] Report, NBS to Secretary of Commerce, Mar. 10, 1943 (NBS Box 482, PRM); RP1705, "Spectrographic determination of boron in steel" (Corliss and Scribner, 1946); Suits, Harrison and Jordan, eds., Applied Physics, Electronics, Optics, Metallurgy, pp. 359–360; NBS War Research, pp. 142–144.

[140] MS Annual Report 1943; NBS War Research, p. 149.

[141] Division V report, January 1943 (NBS Box 488, PRM).

substitute metals included tableware, signal mirrors, and lifesaving equipment.[142]

If in the fall of 1941 the Nation's production capacity in steel was tight, the real pinch was in copper and aluminum. Nation-wide scrap drives brought in millions of domestic pots and pans and cleared cellar collections of nickel, tin, aluminum, copper, brass and other metals, but it was still not enough. To get more copper—the metal of communications systems—the Army in the summer of 1942 furloughed 4,000 soldiers who had previously worked in copper mines.[143]

One substitute for copper, when required as an electrical conductor, is silver, which apart from its high cost is as good and in some cases an even better conductor. As an early expedient, half a billion dollars' worth of silver coins and bullion were borrowed from the Treasury and converted into bus bars, transformer windings and the like.[144] Another copper substitution resulted in the "white" pennies that became common from 1943 on. To satisfy the military demand for copper in its cartridge brass, the U.S. Mint was urged to find something else for the 5,000 tons of copper that went into the 1-cent piece annually. Bureau tests of pennies stamped from zinc-plated steel sheets indicated that they would give at least a few years' service, and over a billion went into circulation. When the bronze coin came back again in 1944, the copper content had been reduced from 95 to 90 percent. Wear and tear, it had been determined, would not be affected, and the public was not likely to notice the difference.

The Bureau also presided over some tampering with the 5-cent piece, changing its composition from 75-percent copper and 25-percent nickel to 50-percent copper and 50-percent silver. It made for a more valuable coin, but at the time copper was precious and silver was noncritical. The addition of a trace of manganese and aluminum made it tarnish-resistant and as acceptable as the original in coin-operated devices.[145]

Unlike copper, in the case of aluminum there were few or no mines to be worked. The industry was small to begin with, and limited domestic

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[142] John E. Burchard, ed., Rockets, Guns and Targets (OSRD; Science in World War II, Boston: Little, Brown, 1948), pp. 357, 396–397; Nelson, pp. 251–252; NBS War Research, pp. 152–156, 170, 179.

Under preliminary development at the Bureau at the end of the war was a unique method of plating by chemical reduction, called "electroless plating," that was to eliminate electrical equipment, deposit coatings of more uniform thickness, and make possible thicker coatings. See Abner Brenner, "Electroless plating comes of age," J. Metal Finishing, 52, 3 (1954).

[143] Nelson, pp. 173–174; Jones, pp. 442–443.

[144] Nelson, p. 355.

[145] Jones, pp. 336–337; NBS War Research, p. 178; interview with Dr. William Blum, Oct. 15, 1963.

supplies of low-silica bauxite, the source of aluminum, meant that 70 percent of all bauxite had to be imported. Urgent investigations were begun under contract at a number of laboratories to develop processes for using some of the less pure bauxite and clays in this country.

At a high-level conference attended by Dr. Briggs and James I. Hoffman in the spring of 1942, it was decided to construct and operate a pilot plant at the Bureau for the extraction of alumina (aluminum oxide) from clays. By autumn both an alkaline and an acid recovery process had been successfully investigated. Pilot plant production started in the alkaline plant under a Bureau team directed by Lansing S. Wells and in the acid plant under Hoffman and Robert T. Leslie.

As the submarine menace waned, increasing supplies of high-grade bauxite ore from the Guianas reduced the need for the new processes. Both, nevertheless, were fully verified in the pilot plant, the alkaline process recovering about 95 percent of the alumina in clay, the acid process resulting in alumina with an average purity of 99.6 percent—almost the equal of that from high-grade bauxite. From May 1943 on, the acid-process plant was in almost continuous operation, finally producing alumina at the rate of 50 pounds a day. In a continuing emergency, large-scale production would have been entirely practicable, but otherwise clay could not compete with the imported ore.[146]

Along with quartz crystal, optical glass appeared on all lists of critical materials. Between the two wars, the Bureau had been the only research organization in the country engaged in both research and production of optical glass, with funds supplied chiefly by the Navy Bureau of Ordnance.[147] Prior to 1940, fewer than 20 people working in the glass plant turned out about 9,000 pounds annually, the entire output going to the Naval Gun Factory for its optical requirements.

With war orders from the Navy, Army Ordnance, Army Engineers, the Treasury's Procurement Division, and OSRD, the optical glass plant expanded. An addition to the kiln building and construction of a second plant with Navy funds more than doubled facilities. The refractories section increased its manufacture of pots from 70 to 2,300 annually, and by working in three shifts production went up from 15,000 pounds of optical glass in 1940 to more than 240,000 pounds in 1942 and in 1943. Even so, the Bureau could not supply more than half the requirements, and Bausch & Lomb, Haywood Optical, and Libbey-Owens Ford furnished the remainder.

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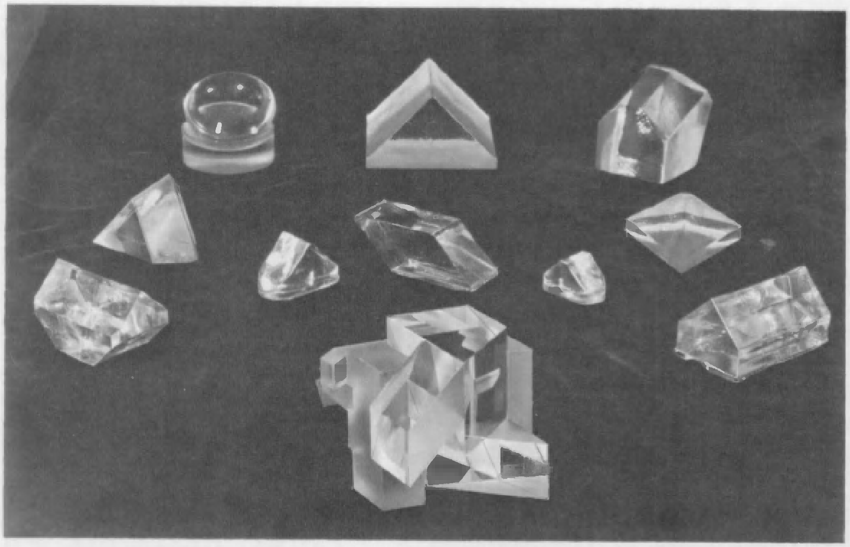
[146] RP1756, "Development of a hydrochloric process for the production of alumina from clay" (Hoffman, Leslie, et al., 1946) ; NBS War Research, pp. 166–168.

[147] Bausch & Lomb began making optical glass in World War I. It maintained its facilities in the interim years, but admittedly "had no appetite for military business in peacetime." See Fortune, 22, 76, 98 (1940) ; memo, GKB for Bureau of Foreign and Domestic Commerce, Feb. 4, 1926 (NBS Box 152, AG).



An assortment of optical glass specimens made at the Bureau. Center bottom is a coincidence prism used in range finders. One of the most intricate and costly of optical devices, it was made at the Bureau by cementing together a number of small prisms.

Of the services, the Navy was the great consumer. A single big rangefinder for one of its guns contained as many as 160 optical elements.

Altogether, the Bureau furnished close to a million pounds of high-quality optical glass to the Armed Forces. Where the Bureau previously made no more than six types of optical glass, military and research requirements called for 28 types before the war ended. At peak production 400 workers under Alfred N. Finn and Clarence H. Hahner were employed around the clock, not only to produce the glass but to mold it into prisms and lenses for readier use in gunsights, heightfinders, periscopes, rangefinders, and binoculars.[148]

In the optics division (optical glass was a product of the ceramics division), investigations were carried out on improved rangefinders, in methods and instruments for testing airplane cameras and lenses, and in optical measurements and materials for camouflaging ships and shore installations. Assistance was also furnished the Navy Bureau of Aeronautics in the design of special aircraft searchlights for use in night attacks on submarines, and in photoelectric equipment for night photography.

A simple yet new and vitally important device that came out of the optics division was the heliographic signaling mirror or "solar searchlight,"

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[148] Hearings * * * 1943 (Jan 12, 1942), p. 208; Hearings * * * 1945 (Jan 11, 1944), p. 189; C469, "Optical glass at the NBS" (Glaze and Hahner, 1948); NBS War Research, pp. 99–101.

as some called it. Early in the war the Joint Chiefs of Staff called for a practical means of aiming reflected flashes at potential rescue craft, both planes and ships, as part of the equipment in liferafts and boats. A member of the Bureau staff at the time, L. L. Young, hit on the rearsight method of aiming mirror flashes, employing reflections from both its front and rear surfaces immediately around a sighting hole in the center of the mirror. Incorporating suggestions made by General Electric, which undertook their manufacture, more than a million of the mirrors, of tempered glass with a surface of vaporized aluminum film, were produced for the air and transport services.[149]

The optics division took part in or carried out alone more than 30 separate investigations, most of them under NDRC auspices. Dr. Briggs's comprehensive report of war research indicates that quite apart from the special groups working for the Manhattan District, on the proximity fuze, on guided missiles, and in radio propagation, each of the other divisions was engaged in as many or more projects as optics. Enumeration of the projects, let alone a description, is beyond the scope of this history. Only a few representative studies can be mentioned.

A laboratory tool of limited interest until the war was a magnetic balance for inspecting certain kinds of steel. Devised by a member of the electrical division in 1932, it was modified by a Bureau chemist 5 years later for gaging the thickness of metal, paint, or enamel coatings on nickel, steel and other metals, making possible nondestructive testing of the coatings. Only a few had been made by the American Instrument Co., under the name Magnegage, until the wartime rash of substitute materials and the necessity of plating made the gages important in many industries, in order to expedite acceptance of military supplies and conserve scarce metals by avoiding the use of unnecessarily thick coatings. Arsenals found the Magnegage invaluable for measuring the thickness of the chromium in the lands and grooves of large caliber guns.[150]

Expansion of Bureau investigations in aviation fuels, lubricants, and motor fuels resulted in greater knowledge of their composition and better control in their production. Many of the war plants making aviation fuels had no previous experience in quality control procedures, and for them the Bureau provided the necessary calibration of primary and reference standard fuels, based on specifications prepared for the American Society for Testing Materials (ASTM), and of "referee" fuels to ensure even quality in production.

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[149] John A. Miller, Men and Volts at War (New York: McGraw-Hill, 1947), p. 104; NBS War Research, pp. 110–111.

[150] RP532, "A magnetic balance * * *" (Sanford, 1932) ; RP994, "Magnetic methods for measuring * * * coatings on nonmagnetic base metals" (Brenner, 1937) ; RP1081, "* * * coatings on iron and steel" (Brenner, 1938) ; NBS War Research, p. 60.

Of fundamental importance was the wartime work of the petroleum laboratory, originally set up in the summer of 1937 with the support of the Army Air Corps, Navy Bureau of Aeronautics, and NACA to synthesize, if possible, an improved aviation fuel. With the war the investigation turned to study of the paraffin hydrocarbons, found as impurities in primary standard reference aviation fuels, and investigation of those of superior value as components of military aviation gasoline. Working with data and samples provided by the American Petroleum Institute, the Bureau laboratory isolated and synthesized some 78 hydrocarbons and prepared 66 of them in a higher purity than ever before.[151] In the case of 21 of the hydrocarbons, no evidence could be found in the literature to indicate they had ever been made before. An added result of the project was the discovery of a possible method for augmenting the supply of aviation gasoline, using re-formed cracked naphtha. Of considerable interest to NACA and the American Petroleum Institute, it became the subject of continued postwar research.[152]

When the early losses of oil tankers by enemy action imperiled the supply of vehicle fuels to our Allies, the Bureau was asked to find out whether substitute fuels from vegetable matter, which the Allies might produce locally, were possible. Attempts to run cars and trucks on gas substitutes was an old story, but the Bureau looked into it again. The studies of engine performance with alcohol, charcoal, shale oil, naphtha, vegetable products and other known substitutes all pointed to alcohol as most promising. Engine tests using gas produced from charcoal showed that approximately 11 pounds of charcoal produced energy equal to a gallon of gas. But the fact that it took 2 minutes to start up the engine and that the little gas generator required

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[151] C461, "Selected values of properties of hydrocarbons" (1947) ; NBS Annual Report 1948, p. 217.

Bureau studies in the chemistry of petroleum oils went back to World War I (see ch. V, pp. 276–277), and cooperative research with the API in the separation of petroleum into its constituent hydrocarbons began in 1928.

The practical problem in the twenties was engine knocking, as compression ratios increased. An octane number scale for expressing the knock rating of motor gasolines was adopted in 1930, with n-heptane for the low and isooctane for the high, and in 1934 the Bureau was asked to set up specifications for these primary standard reference motor fuels. Since that time the Bureau has maintained these national reference standards, on which all octane number measurements throughout the country are based. In 1946 the octane scale was also applied to aviation gasolines.

In the course of its preparation of pure samples, the Bureau found among the aliphatic hydrocarbons several with higher octane numbers than any previously known—the components of later aviation fuels. See RP1027, "Paraffin hydrocarbons isolated from crude synthetic isooctane * * *" (Brooks, Cleaton, and Carter, 1937) ; RP1160, "Properties of purified normal heptane and isooctane * * *" (Brooks, 1938).

[152] NBS Report 2746, "Hydrocarbon synthesis at the NBS, 1937–1953" (Howard, ed., 1953) ; NBS War Research, pp. 75–78; interview with Thomas W. Mears, Apr. 14, 1964.

constant servicing were deemed serious drawbacks. Only alcohol seemed a feasible substitute, and it had to be high proof. Made at the request of the Army, studies of low-proof alcohols showed that a vehicle that got 200 miles on a tankful of standard gasoline and 130 miles with absolute alcohol went only 25 miles on a tank of 70-proof alcohol. The waning of the submarine menace ended the unnerving prospect and the project.[153]

A high-precision wear gage, made by Samuel A. McKee of the Bureau in the course of the substitute fuel study, led to an interesting discovery. The gage itself was capable of detecting as little as one hundred-thousandth of an inch of wear in a motor. While making tests with it, the gage demonstrated, surprisingly enough, that most of the substitute fuels, if not as efficient as gasoline, produced significantly less wear and tear on the engine. It was not the sort of measurement many motorists then or later would be concerned about, but the gage fortunately had other uses.[154]

Another kind of detector, devised at the request of the Air Force and NACA, was the Bureau's carbon monoxide indicator. In place of earlier cumbersome apparatus, Martin Shepherd of the chemistry division produced a sensitive calorimetric indicating gel, put up in a small tube, that quickly signaled the presence of small amounts of carbon monoxide fumes. To produce the tubes, for attachment in the cockpits of fighter planes and crew quarters of bombers, a group of 30 took over a section of the gas chemistry laboratory and set up an assembly line. Over half a million units were turned out and distributed before the highly classified project ended.[155]

In an unceasing search, substitutes for metals were found in wood, concrete, and plastics, and involved a host of products from shower stalls and sinks to fuel oil and gasoline storage tanks. No attempt was made as in World War I to build concrete cargo ships, barges, and tankers, but at the time of the steel shortage the Maritime Commission sought new Bureau studies of reenforced steel, with concrete ships in mind. Instead, the research led to the construction of a number of concrete oil storage tanks before steel plate became available again. Lined with liquid-proofing materials recommended by the Bureau, they were used to store a variety of motor fuels, including high-octane gasoline. Contrary to expectations, losses of gasoline by vaporization through the concrete proved of minor significance.[156]

A challenge to the Bureau was the request made by Military Intelligence to find means of sabotaging enemy construction of concrete fortifications and similar military structures. Was there, Intelligence asked, a readily

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[153] NBS War Research, pp. 79–80.

[154] Ibid.

[155] Shepherd, "Rapid determination of small amounts of carbon monoxide," Anal. Chem. 19, 77 (1947) ; RP1777 (Shepherd, 1947) ; NBS Annual Report 1947, p. 206; interview with Mrs. M. Kilday, May 12, 1964.

[156] NBS War Research, p. 95

available material which, when added in small amounts to concrete while it was being mixed, would inhibit its gain in strength? It could not be too effective or act too fast, lest the sabotage become evident to the builders.

The known inhibitors of concrete strength such as inorganic salts, alkalis, and acids, and even organic materials like dextrose and syrups, failed to meet the specifications. After considerable experimenting the answer was found in common sugar. It was highly effective in a matter of weeks when introduced in fractions of as little as 1 percent.[157] As it happend, most of the coastal fortifications of the enemy were completed when the answer came, and if the military had other uses for the knowledge, the Bureau wasn't informed of them.

The growing importance of plastics that led to formation of the Bureau's organic plastics section in 1935 made that section with its experience the ultimate authority when war came. The War Production Board strongly promoted new plastic products and industry turned them out for the armed services, the Maritime Commission, and the Office of Civilian Defense. Among new plastic products sent for testing were helmet liners, resinous coatings used for protection of steel hardware, bayonet handles, Bureau-designed binocular housings, bugles, canteens, clock housings, compass dials, raincoats, food packaging, goggles, insect screening, shaving brushes, and aircraft housings.

The original helmet liner, made of paper pulp covered with fabric, was far from durable, lost its shape after wetting, and had low resistance to impact. A new liner, on which the Bureau worked with the Office of the Quartermaster General, was constructed of cotton-fabric laminated phenolic plastic, its production one of the first large-scale applications of the low-pressure molding technique. The Bureau also made exhaustive tests of Doron, a glass-fabric laminated plastic, as possible body armor. Some of this personal armor was introduced in the Pacific theater late in the war, after it had been shown superior to an equal weight of steel or metal armor in its ability to stop flak and the small arms fire of most Japanese infantry weapons.[158]

Only the extreme range of qualities sought in textiles and fabrics during the war attempted to compete with the proved versatility of plastics. The armed services, so it seemed to one harassed investigator, wanted textiles that were "infinitely strong and infinitely light, that gave perfect protection against heat and cold and finally were digestible in case of emergency." [159] They wanted fabrics that would keep out a driving rain and yet let perspira-

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[157] NBS War Research, p. 96.

[158] NBS War Research, pp. 119–120.

[159] Ibid., pp. 122–123.

tion through, and they wanted them fireproof, windproof, lightproof, mildewproof, gasproof, and even bulletproof.

Not only the Army, Navy, and Marine Corps, but the War Production Board, National Research Council, Board of Economic Warfare, and Office of Price Administration, sought the aid of the Bureau's textile section under William Appel in creating these fabrics.[160] Since few military fabrics had to possess more than two or three special characteristics simultaneously, the Bureau was able to help, providing much of the technical data that aided in their production. Too difficult even for modern science were the bulletproof and edible fabrics allegedly sought, and a solution to their construction was still not in sight as the war ended.

Among the many problems posed Scribner's paper section was a new paper for war maps, requested by the Corps of Engineers. In some of the swift-moving operations in the later stages of the war in Europe, deterioration of much-used maps became as troublesome as running off the edges of the maps at hand. Not long before that, however, the problem had been licked by production of a unique fiber-binding resin paper of great strength, capable of withstanding treatment that quickly disintegrated ordinary map papers. Maps printed on it remained serviceable even when soaked with water or oil and after being trampled in mud and subsequently washed with soap and water or gasoline. All agencies making war maps in this country adopted the new paper as standard and quantities of it were sent to Great Britain under Lend-Lease.[161]

Few were the crises of supply faced in World War I that did not have to be met again in 1940. A conspicuous exception was that of high precision gage blocks, making possible mass production of interchangeable parts. At least 10 manufacturers undertook to turn them out in quantity for industry, and as a result of queries, the Bureau prepared a letter circular for manufacturers and gage users providing criteria for the acceptance or rejection of gage blocks.[162] As early production difficulties were solved, the Bureau thereafter had only the responsibility for calibrating the blocks. Altogether, more than 76,000 gage blocks and accessories, both English and metric, passed through the Bureau's hands for the gage manufacturers, the armed services, war plants, and the Procurement Division. Of more than 24,000 certified in 1944 alone, 50 percent went to the U.S.S.R. by way of Treasury's Lend-Lease.[163]

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[160] OSRD interest in this Bureau research, particularly in tropic-proofing and light-proofing of textiles, is briefly reported in W. A. Noyes, Jr., ed., Chemistry (OSRD: Science in World War II, 1948), pp. 470–471.

[161] NBS War Research, pp. 126–127; RP1751, "Experimental manufacture of paper for war maps" (Weber and Shaw, 1946).

[162] LC725 (1943).

[163] MS Annual Report 1944, n.p.

Tens of thousands of other types of gages and measuring instruments were calibrated in the Bureau's expanded gage section. A handbook on screw thread standards, originally issued in 1939, was revised in 1942 and again in 1944, to keep up with the improvements in thread standards that evolved during the war.[164] In other sections of the metrology division the certification of standard weights, volumetric glassware, thermometers and other instruments soared as laboratories were set up or expanded in industry and as war plants came into production. Almost 100,000 standard samples of steels, irons, alloys, ores, ceramics, chemicals and hydrocarbons, oils, paint pigments, and other substances were distributed during the period, representing a fourfold increase over the prewar rate.

Little publicized, yet significant in the conservation of critical materials, was the wartime effort of the simplification and commercial standards groups at the Bureau. At the beginning of the defense program in 1940 a number of industry advisory committees were set up as liaison between industry and Government on simplification. Simplified practice recommendations made by these committees were incorporated in regulations issued by the Office of Price Administration and later in the orders of the War Production Board, resulting in important savings in labor, machines, and both critical and noncritical materials.[165]

WPB orders limiting the sizes and weights of tubular radiators, for example, were estimated by that agency to have saved 23,000 tons of cast iron. Builders' hardware was reduced from approximately 27,000 to 3,500 items. Sixty-five percent of all types and sizes of brass and bronze pipe fittings were eliminated and the variety of brass and bronze valves was reduced from 4,079 to 2,504 types, saving thousands of tons of carbon steel, copper, and alloy steel.

Forged axes, hammers, and hatchets were reduced from 636 to 303 types, conserving vital alloy steels, and all use of these steels as well as high-polished finishes were eliminated from rakes, hoes, and forks, while their variety and sizes dropped from 915 to 129 types. Wrenches and pliers were reduced to one style and one grade per manufacturer.

In order to concentrate manufacture on fewer essential types, dental excavating burs were mercifully reduced from 75 to 24 sizes, though all of them, from the point of view of the patient, may still have seemed too large. Other products similarly affected included concrete-reenforcement steel,

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[164] H25, "Screw-thread standards * * *" (1939, superseded by H28, 1942, and revised in 1944); NBS War Research, pp. 163–164. MS Annual Report 1944 reported that 53,000 copies of H28 were sold.

[165] For industry's reaction to "defrilling" (it approved, but warned its members against voluntary standardization without clearing with a defense agency), see Business Week, Nov. 22, 1941, p. 17, and May 1, 1943, p. 30.

forged hand tools, wood saws, plumbing and heating tanks, refrigerator valves and fittings, shovels and spades, and welded chain.[166]

Among new commercial standards dictated by the war, porcelain-enameled steel utensils replaced the aluminum, stainless steel, and copper pots and pans that were donated to the scrap drives. Extensive use was made for the first time of plywood and fiberboard in the construction of barracks, concrete forms, boats, pontoons and other normally all-wood products. Mineral wool and fiberboard also proved satisfactory and in some cases superior replacements for cork as insulation materials.[167] What with victory gardens, meatless Mondays, and ration books, the war was only months old when it became evident that life on the homefront was to be a matter of substitutes, do-it-yourself, or do without.

Of the hundreds of consumer products merely simplified out of existence by the war, most conspicuous was the automobile. A War Production Board order of January 20, 1942, stopped all production of cars and light trucks. The last passenger car rolled off the assembly line 3 weeks later. Domestic refrigerators came under severe curtailment next, and in a sweeping order in May, the manufacture of more than 400 other civilian products using iron and steel ceased.[168] The great conversion to war production had begun.

An index to the vast potential of production in this country on the eve of war, though it was concealed by the doldrums in which industry continued to languish and by the great pool of the unemployed, appeared in the incredible rapidity with which the Nation became fully armed and supplied for global warfare. By September 1943, hundreds of huge new rubber, steel, petroleum, aluminum, and magnesium plants had arisen and began reaching full-scale operations where fields or forests had ruled before. Tanks, guns, shells, tires, aircraft, and great catalogs of miscellaneous supplies and parts were pouring along assembly lines to waiting freight trains headed for the ports of embarkation. Supplies and equipment that did not cross with troopships filled convoys for the arming of the British, French, and Russians, or for the stockpiles that were being crammed into the English countryside.

November 1943 marked the high point in war production. Thereafter it began to slope downward. The successive targets for production of raw materials and finished products set during the preceding 3 years had been

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[166] Nelson, p. 240; NBS War Research, pp. 172–173. In some instances sales to industry of the simplified practice recommendations for these products ranged as high as 25–30,000 copies. Many had to be reprinted later to meet the continuing postwar demand. See NBS Annual Report 1946, p. 207.

[167] NBS War Research, pp. 173–174.

[168] Nelson, pp. 224, 283.

met.[169] With the consolidation of the Normandy peninsula, the word "reconversion" was heard for the first time. The supply lines were full and could be maintained with some slacking in production, even though the strategic planning staff foresaw the war against Japan lasting into 1947.

When V–J Day came on August 14, 1945, 3 months and 6 days after victory in Europe, American industry had produced 86,000 tanks, 296,000 planes, 4,800 merchant ships, and 71,000 ships for the Navy. In August and September of 1945 the Army sent out 30,000 telegrams canceling defense contracts and reconversion began.[170] Two months later, in November 1945, the Bureau began its own reconversion—in organization, staff, and program—to research in the postwar world.

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[169] Nelson, p. 395. Besides new magnesium and synthetic rubber industries, between 1939 and 1945 aluminum production was tripled, machine tool capacity increased sevenfold, electrical output rose one and a half times its prewar rate, and more iron and steel were produced than in the entire prewar world. The total plant production in the Nation almost doubled. Freidel, America in the 20th Century, p. 400.

[170] Kenney, The Crucial Years, 1940–1945, p. 100.

The standard avoirdupois pound of Queen Elizabeth I, which is believed to have originally weighed about 7,002 troy grains. It was used as a British standard from 1588 to 1825.