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## History of Synthetic Rubber

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## History of Synthetic Rubber

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### ABSTRACT

Synthetic rubber undoubtedly represents the earliest development of the synthesis of macromolecules. It dates back to the historic discovery by Greville Williams in 1860 that isoprene is the "mother substance" of natural rubber. Attempts to convert isoprene, and later other 1,3-dienes, to a synthetic rubber began shortly thereafter, although the first commercial production of such a material did not take place until a half century later. The period between World War I and II witnessed the first development of a true synthetic substitute for natural rubber, i.e., sodium-polymerized butadiene, which was produced in Germany as Buna rubber and in the USSR as SK rubber. However, during the 1930s, Germany developed the emulsion copolymerization of butadiene-styrene (Buna S), whereas sodium polybutadiene continued as the principal general purpose synthetic rubber in the Soviet Union. The United States which, up till then, had only developed special-purpose synthetic rubbers like neoprene, entered the synthetic rubber age during the emergency of World War II when natural rubber supplies were cut off, and developed a giant industry based on Buna S technology virtually overnight.

Among the synthetic polymers in use today, synthetic rubber is unique in that it was developed not as an interesting new material but

to fill a dire need of the modern world. As a matter of fact, here in the United States, it arose solely out of the emergency of World War II.

The reason for this unique position of synthetic rubber is, of course, the unique property of rubber, the only substance which exhibits long-range elasticity, and which therefore fills a special need in modern technology. Natural rubber was discovered in the New World as early as Columbus's voyages, but its use in technology did not really take place until after the Industrial Revolution, i.e., with the start of the 19th century. However, it was not until the latter part of the last century that the first attempts were made to synthesize rubber from simple chemical compounds.

### EARLY HISTORY

The name "rubber," which is used only in the English language (all other languages use some form of the original American Indian name "caa-ochoe"), is said to have arisen from the discovery in 1770 by Joseph Priestley (better known for his "other" discovery of oxygen) that rubber can erase pencil marks. It might have been the unusual properties of this unique elastic material which prompted Michael Faraday in 1826 to determine its chemical composition as  $C_5H_8$ . Although it was at that time that natural rubber began to be used more extensively in manufacturing, nothing further was known about its chemical structure until 1860, when Greville Williams [1] carried out his extensive pyrolysis studies at the University of London, and showed that this substance consisted of the basic compound isoprene and homologs thereof.

It is not surprising, therefore, that various attempts were subsequently made by enterprising chemists to "convert" isoprene into rubber. Among the more noteworthy efforts were those of Bouchardat [2], in 1879, who actually formed a rubberlike substance by heating isoprene in the presence of hydrochloric acid, and Tilden [3], in 1884, who did the same but with isoprene not obtained from the pyrolysis of natural rubber. These explorations were soon followed by the work of Kondakow [4] (1900) with 2,3-dimethylbutadiene, Thiele [5] (1901) with piperylene, and Lebedev [6] (1910) with butadiene. Probably the most significant developments of this period, however, were the discoveries by Matthews and Strange [7], in 1910, that isoprene can be polymerized by means of sodium, and by Harries [8], in 1913, that butadiene can be polymerized in the same way.

These early researches might be said to have led to the first large-scale production of synthetic rubber which occurred in Germany during the blockade-induced emergency of World War I. This "Methyl Rubber" was produced by the thermal polymerization of 2,3-dimethylbutadiene (obtained from acetone) in the presence of air at temperatures of 30-70°C for times varying from 2 to 6 months! A total of

2350 tons of this material was actually produced, but it had such poor properties that it died a natural death at the end of the war. Whitby and Katz [9] have pointed out that the miserable failure of this fledgling synthetic rubber was largely due to the absence at that time of knowledge concerning the marked reinforcing effect of large amounts of carbon black in rubber compounding.

Research on synthetic rubber prior to World War I was not only spurred by strategic national considerations but by economic ones as well. Thus, due to the rise of the automobile industry, especially in the United States, the demand for rubber could not always be met, and although world production of natural rubber (mainly from the plantations) rose from 44,000 tons in 1900 (at about \$1 per pound) to 94,000 tons in 1910, the price still hit a peak of about \$3 per pound! It was these recurring shortages, as well as wildly fluctuating prices, that aroused a great deal of interest in synthetic rubber, not only in Europe but also in the United States, which, at that time, was consuming about 3/4 of the world supply of rubber.

## RUBBER AND MACROMOLECULES

The efforts in synthetic rubber research took on a new character following the end of World War I because of the rapid expansion in knowledge about rubber and other polymers. This was largely due to the initiative of Hermann Staudinger, who relentlessly pursued his macromolecular hypothesis during the 1920s. Prior to that time it was the general consensus that natural rubber was a "colloidal" substance in which the rubber molecules are aggregated into large "particles." The "true" molecule of natural rubber was generally assumed to be a cyclic dimer or trimer of isoprene but aggregated to an immeasurably high "molecular weight." (Many of the chemists of that period were engaged in a fruitless search for a suitable "solvent" that would break down the colloidal aggregates to their true, measurable molecular weight.)

In 1910, Pickles [10] carried out a classical experiment in which he showed that bromination of rubber did not affect its "colloidal" character. Since it was assumed that the double bonds in the isoprene were responsible for the forces causing molecular aggregation, bromination should have destroyed such aggregation. The fact that it did not led Pickles to the conclusion that the true rubber molecule was indeed larger than a dimer or trimer of isoprene, but he still clung to the idea of a large ring. It was Staudinger [11] who, in 1920, first proposed the existence of "macromolecules" as long-chain molecules. Then, in 1922, in experiments analogous to those of Pickles, he demonstrated that the hydrogenation of rubber did not change the "colloidal" properties of rubber solutions, thus indicating that the "colloidal particles" are indeed macromolecules held together by primary valence bonds [12].

## SYNTHETIC RUBBER DEVELOPMENTS AFTER WORLD WAR I

### USSR and Germany

There is no doubt that the development of synthetic rubber during the 1920s and 1930s was markedly accelerated by a better understanding of macromolecules. In both the USSR and Germany, the polymerization of butadiene by sodium was developed into a commercial process during the 1920s, although not immediately for tire use. Thus arose the first of the "Buna" synthetic rubbers, as implied by their name. By the end of that decade, however, the Germans had turned their attention to the more attractive process of emulsion copolymerization of butadiene and styrene, and the basic patents on Buna S, as it was called, were issued in 1933 to Tschunkur and Bock [13] of the Leverkusen works of I. G. Farbenindustrie. At the same time, patents on the emulsion copolymerization of butadiene and acrylonitrile were issued to Konrad and Tschunkur [14] of the same organization.

The actual large-scale production of the two general purpose synthetic rubbers, i.e., sodium polybutadiene in the USSR and Buna S in Germany, only started in the 1930s, and is shown in Table 1. It can be seen that Russian production rose rapidly during these years, and is said to have reached a value of 125,000 long tons in 1941. In this connection, it is interesting to speculate about the sharp drop in production of SK rubber in 1937. Was this a direct result of the notorious purges of political and administrative staff started by Stalin during 1936?

TABLE 1. Synthetic Rubber Production in the USSR and Germany Prior to World War II (long tons)

Year	USSR (SK rubber <sup>a</sup> ) [15]	Germany (Buna S) [16]
1933	2,204	-
1934	11,139	-
1935	25,581	-
1936	44,200	-
1937	25,000	2,100
1938	53,000	4,000
1939	78,500	20,600

<sup>a</sup>Sodium polybutadiene.

Developments in the United States

During this period there was little or no interest in the United States in the development of a general purpose synthetic rubber, mainly because of economic considerations. Thus the price of natural rubber, which was generally about 15¢ per pound, dropped to a low of 2.7¢ during the depressed year of 1932. (There was a similar lack of interest in such countries as Great Britain, France, and Holland, but mainly because of their extensive holdings in the rubber plantations of the Far East.) However this did not prevent the development, in the United States, of such specialty rubbers as neoprene and Thiokol, which showed unusual resistance to swelling by hydrocarbon solvents. Thus the former, polychloroprene, obtained by the emulsion polymerization of 2-chlorobutadiene, was first produced commercially in 1932 in the amount of 250 tons by the Dupont Co. as Duprene and fetched a price of \$1.00 per pound. Similarly, Thiokol, a polyalkylene polysulfide obtained by the condensation of alkylene dichlorides with sodium polysulfides, was first produced (2 tons) in 1930.

It was during this period, however, that the United States acquired the necessary technology which was to prove so important in the production of Buna S during World War II. In 1929 the Standard Oil Co. of New Jersey entered into an agreement [17] with I. G. Farbenindustrie for the use of their technology for the hydrogenation of coal and oil. This was based on an estimate [18], made in 1926, that the United States had only a 7-year supply of petroleum fuels! It is interesting to note that the estimated cost of producing such synthetic gasoline at that time was 15-20¢ per gallon, and that this was not considered as competitive with gasoline from petroleum crude. As part of the agreement, Standard Oil was also to have access to any patents on new products derived from these hydrocarbons, including the Buna S developments. It was this latter arrangement, rather than the coal hydrogenation technology, which was later to prove of such importance to the United States.

Another development pioneered by the Standard Oil Co. just before World War II was the invention of butyl rubber by Thomas and Sparks [19]. This synthetic rubber was based on the isobutylene polymers developed in Germany, e.g., Vistanex, but modified by copolymerizing a small proportion of a diene, such as isoprene, with the isobutylene in order to introduce just enough unsaturation for sulfur vulcanization. Because of the limited unsaturation present in these rubbers, they were of special interest for oxidation and weather resistance.

#### WORLD WAR II AND THE U.S. SYNTHETIC RUBBER PROGRAM

By the end of 1941, when Japan entered the war and threatened the natural rubber supply from the plantations of Southeast Asia, the rubber situation in the United States was as follows:

1. Annual consumption of rubber was about 600,000 tons.
2. A natural rubber stockpile of about 1 million tons had been accumulated.
3. An annual production of 40,000 tons of general purpose synthetic rubber had been authorized by the government, to be produced by the four large rubber companies.

In January of 1942, after the rubber plantations of Southeast Asia had been virtually taken over by Japan, the above production goal for synthetic rubber was immediately increased to 800,000 tons per annum. However, because of the usual bureaucratic delays and the arguments in both houses of Congress, nothing was really accomplished until President Roosevelt, in August 1942, appointed a special committee to investigate the "rubber situation." The chairman of this committee was the well-known financier, Bernard M. Baruch, and the two other members were Dr. James B. Conant, President of Harvard University (a chemist), and Dr. Karl T. Compton, President of Massachusetts Institute of Technology (a physicist). This Rubber Survey Committee took only 1 month to carry out its work and on September 10, 1942, it submitted its report and recommendations to the President. A picture of the general situation then prevailing is given by the following excerpt [ 20 ] from the introductory part of this report.

Of all critical and strategic materials, rubber is the one which presents the greatest threat to the safety of our nation and the success of the Allied cause. Production of steel, copper, aluminum, alloys or aviation gasoline may be inadequate to prosecute the war as rapidly and effectively as we could wish, but at the worst we still are assured of sufficient supplies of these items to operate our armed forces on a very powerful scale. But if we fail to secure quickly a large new rubber supply our war effort and our domestic economy both will collapse. Thus the rubber situation gives rise to our most critical problem.

Our position with respect to this vital commodity may be briefly outlined as follows:

The demands now placed upon us are enormous. Without any allowance whatsoever for civilian passenger car tires the estimated requirements for the year 1943 are 574,000 tons. This contrasts with the total average over-all consumption in the United States before the war of over 600,000 tons. We must supply not only the needs of our own armed forces but much of those of the military machines of our Allies as well. We must equip our buses and trucks and other commercial vehicles and provide on a large scale specialty items for such purposes as factory belting, surgical, hospital and health supplies. And in addition to all these we must maintain the tires on at least a substantial portion of our 27,000,000 civilian passenger automobiles. Otherwise, an economy geared to

rubber-borne motor transport to an extent not approached elsewhere in the world will break down.

One of the key recommendations of the report was the appointment of a Rubber Director, to have complete authority in all matters dealing with the supply and use of rubber, including the immediate construction of facilities to produce 845,000 tons of Buna S type synthetic rubber. As a result, the U.S. Government invested about \$700 million in building 51 plants for the production of the monomers and polymers needed for the manufacture of synthetic rubber. These plants were built and operated, both during and after the war, by staff of the American rubber companies in behalf of the government. The production figures for Buna S type synthetic rubber (called GR-S as a "government rubber") during those crucial war years are shown in Table 2. The "production miracle" during 1943 and 1944 is clearly evident, considering that a giant new chemical industry was thus established in 2 years' time. This accomplishment of American technology was only overshadowed by the subsequent development of the atomic bomb.

#### THE U.S. GOVERNMENT SYNTHETIC RUBBER RESEARCH PROGRAM

According to Howard [ 22], when the Standard Oil Development Co. made the German Buna S patents available to the United States government, it only asked in return that the government invest \$5 million in establishing and supporting a synthetic rubber research program. This was started at the inaugural meeting of the "Rubber Research Discussion Group" of the Copolymer Research Section, Office of

TABLE 2. Production of Buna S (GR-S) (1939-1945) [ 21] (thousands of long tons)

Year	USA	Canada	Germany
1939	-	-	20.6
1940	-	-	37.1
1941	0.23	-	65.9
1942	3.7	-	94.2
1943	182.3	2.5	110.6
1944	670.3	32.1	97.5
1945	719.4	36.6	-



Assistant Deputy Rubber Director for Research and Development of Synthetics, held at Akron, Ohio, on December 28-29, 1942. The objective of the government was of course to recruit as many as possible of the leading academic and industrial scientists to direct their attention to the scientific problems involved in the total replacement of natural rubber. As will be seen later, this objective was only attained 14 years later, at which time the government program was terminated. A list of the participants in the above 1942 inaugural meeting is shown in the Appendix, together with their affiliations. Several other organizations later joined the program, such as the National Bureau of Standards, Mellon Institute, and Franklin Institute. In addition to Professor Harkins, the University of Chicago also contributed two other renowned chemists, Prof. M. Kharasch in organic reactions and Prof. W. Heller (later at Wayne State University) in physical and surface chemistry. Cornell University was also a subsequent participant through Prof. P. Debye, and later Prof. P. J. Flory. This description should not be construed as an attempt to list all the participants during the 14-year life of the program.

The responsibilities of the research program to the solution of critical short-term and long-term problems of the synthetic rubber industry are dramatically illustrated by the opening remarks of the Chairman at the inaugural Akron meeting, Prof. R. R. Williams, a portion of which is reproduced below.

We are particularly concerned here with the prosecution of research. In this connection one fact needs all possible emphasis; namely that the most critical period with respect to rubber supply is only eight months away. Our stock pile of natural rubber, in spite of every effort at economy and conservation, is being steadily whittled away. By August or September, in spite of all that we can probably do with the production of synthetic rubber, our stock of all sorts will fall to the neighborhood of 100,000 tons, which is not greatly in excess of the amount of rubber inventories of material actually in process of manufacture in the various defense and essential civilian industries. Imagine, if you can, what a public clamor we shall face when, as and if there is an accumulation of guns, trucks, planes and other military equipment awaiting only rubber parts for their completion and delivery. Imagine how desperate will be the plight of defense industry workers once their own tires and those of the bus lines which might otherwise transport them, are worn out.

The principal scientific problems posed by the use of butadiene-styrene copolymer (GR-S) in place of natural rubber can be listed as follows:

- a) Greater processing difficulties, i.e., slower breakdown and softening during mastication and compounding.

- b) Lower rupture strength, i.e., tensile, tear and abrasion, also greater crack propagation.
- c) Poorer dynamic properties, i.e., greater temperature rise during flex cycling.

As more was learned about the behavior of GR-S, the problems listed under a) and b) above were gradually solved. Thus the use of various chemical agents was introduced to assist the mechanical breakdown of the polymer, while the development of new types of carbon black as reinforcing agents led to marked improvements in the rupture strength of these synthetic rubbers. However, the problem described under c) above, i.e., the inferior resilience of GR-S compared to natural rubber, was never completely overcome. Hence the resulting heat "build-up" made it impossible to replace natural rubber entirely in large tires, such as those used for trucks, etc., although this could be done for the usual passenger car tires.

In this connection it is interesting to note the differing philosophies which pervaded the American and German synthetic rubber industries. It is a known fact that the introduction of emulsion polymerization in Germany during the 1930s enabled the attainment of very high molecular weights in the butadiene-styrene copolymer (Buna S). Because of these very high molecular weights (>1 million), it was found that sufficient cross-linking occurred between the unsaturated polymer chains to lead to insoluble networks ("gel"), resulting in a tough elastomer, difficult to process. To obviate this difficulty, the use of chain-transfer agents, e.g., thiols or disulfides, during polymerization was introduced in order to reduce the molecular weight and prevent gel formation. However, since such a reduction in molecular weight was known to lead to some loss in mechanical properties of the final vulcanizate, the use of chain transfer agents was kept at a minimum in Germany, even though this posed problems in processing of the rubber compounds. In contrast, in the United States, production schedules were (and still are!) considered most important, and the synthetic rubber industry was asked to supply the rubber product industry with the most processible polymer, even at some sacrifice of end-product quality. Two different philosophies!

#### DEVELOPMENTS IN THE UNITED STATES AFTER WORLD WAR II

Since rubber had been designated as a "strategic and critical" material in 1940 [23], the U.S. Government was committed to maintain and support the synthetic rubber industry and synthetic rubber research until such time when natural rubber could be completely replaced, if necessary. Hence both production and research continued under government support after the end of World War II. With regard to the GR-S type of synthetic rubber, the two major

postwar developments, both of which were introduced by 1950, were 1) "cold" rubber and 2) oil-extended rubber. Shortly thereafter there was, of course, the breakthrough into stereospecific polymerization which led to the synthesis of cis-1,4-polyisoprene, finally achieving the century-old dream of the duplication of natural rubber.

### "Cold" Rubber

Even before the end of the war, it had been felt that there should be advantages in reducing the temperature of polymerization of GR-S from the usual 50°C in order to reduce undesirable side reactions, such as cross-linking. To this end considerable research was in progress in an effort to discover initiators which could operate at lower temperatures, e.g., ~0°C. By war's end, some of these initiators, e.g., organic hydroperoxides, had already been found promising, and new information subsequently obtained from Germany showed that such initiators had already been put into use to make "cold" rubber in that country. Thus it became possible, by carrying out the polymerization reaction at about 5°C, to produce GR-S of much higher molecular weight without encountering any gel. A scientific study at that time [24] clearly demonstrated that the cross-linking reaction could be reduced by a factor of 5 or 6 by such a drop in polymerization temperature.

### Oil-Extended Rubber

Although the "cold" rubber produced at these low temperatures was a gel-free high molecular weight material of improved physical properties, it still posed problems in processing because of its high viscosity. To this end, the idea of "oil-extension" was developed whereby 25-30% of an inexpensive petroleum oil fraction was incorporated into the GR-S, in latex form, prior to coagulation, thus plasticizing the high viscosity polymer. In this way, "cold" GR-S of 100 Mooney viscosity could be reduced to a 50 Mooney polymer, making it readily processible, and at the same time simultaneously increasing the yield of rubber and reducing its cost without sacrificing the physical properties!

### Stereospecific Polymerization of Synthetic Rubber

In 1954, reports began to circulate about the new polymerization catalysts developed and used by K. Ziegler in Germany and G. Natta in Italy, and which were capable of producing both linear polyethylene and stereoregular polypropylene ("isotactic" and "syndiotactic"). Shortly thereafter it was announced by the B. F. Goodrich Co. of Akron, Ohio, that S. E. Horne and co-workers [25] had succeeded, by

means of these same types of catalysts, in polymerizing isoprene to a virtually all *cis*-1,4 polymer, thus duplicating, to all intents and purposes, the molecular structure of Hevea rubber. At about the same time, the research group at the Firestone Tire and Rubber Co. in Akron (F. W. Stavely and co-workers [26]) announced that they had accomplished the same objective by means of lithium (metal or organometal), although admittedly not achieving quite as high a *cis*-1,4 content.

The interesting aspect of these investigations was the highly specific mechanisms of these catalysts. Thus lithium catalysts, which were capable of producing polyisoprenes of very high (>90%) *cis*-1,4 content, did not show the same stereospecificity in the case of butadiene, producing a polymer chain of mixed *cis*-1,4, *trans*-1,4, and 1,2 structures. (The latter type of polybutadiene has nevertheless become a commercial synthetic rubber on its own.) On the other hand, by a slight alteration of the Ziegler-Natta type catalyst used for the synthesis of *cis*-1,4-polyisoprene (substituting titanium tetraiodide for titanium tetrachloride in the  $\text{AlR}_3/\text{TiX}_4$  complex), it was found possible [27] to polymerize butadiene also to a virtually all *cis*-1,4 configuration.

The U.S. Government program, both as regards synthetic rubber production and research, was of course markedly influenced by all of these developments of the 1950s. Thus the superior properties of "cold" rubber in automobile tire treads, and the good economics of oil-extended rubber, made GR-S competitive with natural rubber even after the end of the war. In 1955 the government took the necessary steps to sell all of its synthetic rubber facilities to various private companies, both big and small. Then, following the breakthrough in the synthesis of *cis*-1,4-polyisoprene described above, the government research program was terminated on June 30, 1956, with the proviso that some of the program funds be transferred to the fledgling National Science Foundation to enable the latter to continue support of some of the academic polymer research projects.

#### SCIENTIFIC "SPIN OFFS" FROM THE U.S. GOVERNMENT SYNTHETIC RUBBER RESEARCH PROGRAM (1942-1956)

The government-supported synthetic rubber research program was undoubtedly unique in United States history, taking into account its size, scope, and duration. Within this program it was possible for the academic scientists, as well as some of the industrial scientists, to carry on fundamental studies of their own choosing with a minimum of bureaucratic interference. The opportunity of academic and industrial scientists to meet frequently (at least semiannually) for several days to exchange information freely helped greatly to stimulate creative new ideas. This was especially important since this program took place at a time when the science of macromolecules was truly in

its infancy. Hence it is not surprising that the basic knowledge which was gained from this research was not only relevant to synthetic rubber but to macromolecules in general. The following list of some of the "spin-offs" that resulted from this program is quite instructive:

1. Determination of size and shape of macromolecules in solution by light scattering (Debye).
2. Chain dimensions and configurations of macromolecules in solution and in the bulk state, based on solution viscosity and rubber elasticity (Flory).
3. Dynamic behavior of polymers in solution and in the bulk state (DeWitt, Marvin, Markovitz).
4. Infrared spectroscopic analysis of polymer chain structure (Richardson and Sacher, Binder, Field).
5. Mechanism and kinetics of emulsion polymerization (Harkins, Kolthoff, Ewart and Smith, Morton).

All of the above contributions led to the rapid advances of polymer science that we have witnessed during the past 30 years. As for the practical objective of the government synthetic rubber program, i.e., to make the United States independent of natural rubber, that was of course accomplished by the breakthrough in stereospecific polymerization. Yet that, too, was an outcome of the fundamental knowledge emanating from the whole research program. Thus, for example, if it were not for the development of infrared spectroscopy for chain structure determination, it would have been far more difficult, if not impossible, to pursue, in a systematic fashion, the synthesis of cis-1,4-polyisoprene.

## SYNTHETIC VS NATURAL RUBBER

Although the synthetic rubber industry in the United States, the largest such industry in the world, was born of wartime emergency, it fulfilled a future need. This was also mirrored by the rapid rise of such industries in virtually all parts of the world. The situation today is therefore markedly different from that which prevailed prior to World War II. At that time, world production of natural rubber was about 1.5 million tons, of which the United States consumed over 50%. Synthetic rubber was only produced in substantial quantities by the USSR and Germany, and totaled no more than 100,000 tons or so. Today world production of natural rubber is about 4 million tons, while synthetic rubber totals about 7 million tons! The United States alone produces and consumes about 2.5 million tons of synthetic and uses about 3/4 million tons of natural rubber.

These figures show dramatically the sharp increase in world consumption of rubber. It is obvious that natural rubber alone could

not have met this soaring demand, and that it is the rise of synthetic rubber production that was needed both to fill the need and to maintain economic stability. Can we apply this lesson to today's monopolies and soaring prices of "natural" petroleum resources?

## APPENDIX

Excerpt from Report No. CR-2, War Production Board, Office of Assistant Deputy Rubber Director for Research and Development of Synthetics, Copolymer Research Section, February 1, 1943.

Rubber Research Discussion Group

Mayflower Hotel, Akron, Ohio

December 28-29, 1942

R. R. Williams, Chairman

Baker, W. O., Bell Laboratories  
Bebb, R. L., Firestone Tire & Rubber Co.  
Biggs, B. S., Bell Laboratories  
Borders, A. M., The Goodyear Tire & Rubber Co.  
Carr, E., Firestone Tire & Rubber Co.  
Clifford, A. M., The Goodyear Tire & Rubber Co.  
Crawford, R. A., The B. F. Goodrich Co.  
D'Ianni, J. D., The Goodyear Tire & Rubber Co.  
Dillon, J. H., Firestone Tire & Rubber Co.  
Dunbrook, R. F., Firestone Tire & Rubber Co.  
Ewart, R. H., United States Rubber Co.  
Flory, P. J., Esso Laboratories  
Frolich, P. K., Esso Laboratories  
Fryling, C. F., The B. F. Goodrich Co.  
Fuller, C. S., Office of Rubber Director  
Garvey, B. S., Jr., The B. F. Goodrich Co.  
Gehman, S. D., The Goodyear Tire & Rubber Co.  
Harkins, W. D., University of Chicago  
Haworth, J. B., Esso Laboratories  
Howland, L. H., U. S. Rubber Co.  
Japs, A. B., The B. F. Goodrich Co.  
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Kolthoff, I. M., University of Minnesota  
Marvel, C. S., University of Illinois  
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Prupton, C. F., Case School of Applied Science  
Semon, Dr. W. L., The B. F. Goodrich Co.  
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 Street, J. N., Firestone Tire & Rubber Co.  
 Stewart, W. D., The B. F. Goodrich Co.  
 Swaney, M. W., Esso Laboratories  
 Taylor, H. S., Princeton University  
 Tobolsky, A., Princeton University  
 Walton, C. W., The Goodyear Tire & Rubber Co.  
 Whitby, G. S., University of Akron  
 Wiegand, W. B., Columbian Carbon Co.  
 Williams, R. R., Office of Rubber Director

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