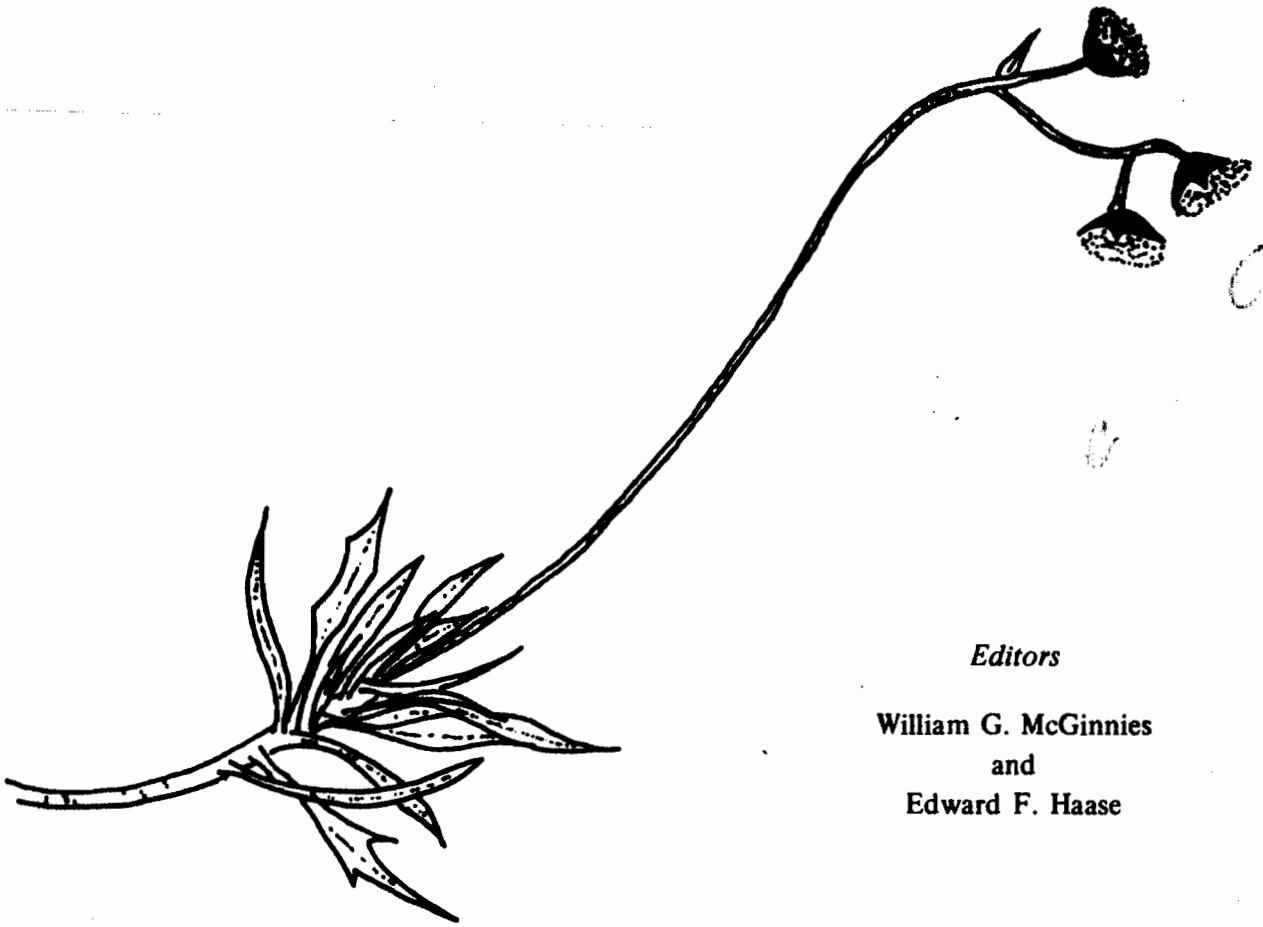
An International Conference on the Utilization of Guayule



Editors

William G. McGinnies
and
Edward F. Haase

November 17-19, 1975
University of Arizona
Tucson, Arizona

AN INTERNATIONAL CONFERENCE ON THE UTILIZATION OF GUAYULE

Proceedings of Meeting
held at
Tucson, Arizona
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William G. McGinnies and Edward F. Haase, editors

Preface

It was decided that the proceedings of the guayule conference would be limited to technical presentations and pertinent comments either made verbally during the conference or submitted in writing. Introductory remarks have been eliminated. Because of financial restraints only a limited amount of illustrative material could be included. In cases where slides or other projected material were used by the speaker, the editor rewrote the transcribed talk. Usually this resulted in a shorter account or even a brief summarization.

Where a paper was turned in it was used for the proceedings along with any off-the-cuff remarks that seemed appropriate.

Wherever possible, the person asking a question or making a comment has been identified, but in many cases this was impossible.

TABLE OF CONTENTS

Page

Introductory Remarks 1

Guayule Production Prior to World War II 3

Illustrated Review--Emergency Rubber Project 9

Post World War II Guayule Activities 13

Guayule Seed Treatment and Nursery Practices--1942 20

Field Production and Harvesting 26

Propagation from Cuttings 32

Experimental Plantings in Israel 32

Report on Activities of the Continental Mexican Rubber Company 37

Diseases of Guayule 38

Review of World War II Extracting and Processing Guayule Rubber 41

Comments on Rubber Extraction and Utilization 52

Deresination of Guayule Rubber 60

Recent Rubber Production Activities in Mexico 71

Physiology and Chemistry of Guayule 78

Soil-Plant Relationships--Guayule 83

Climatic Relationships in the Growth and Production of Guayule 94

California Indicator Plots 1942-43 104

Results from the New Mexico and Texas Guayule Indicator Plots 109

Experiments with Guayule in Arizona 110

Genetics and Plant Breeding 111

Genetic and Agronomic Research 118

Plant Breeding 120

Market Potential and Economic Production 122

Retting 146

TABLE OF CONTENTS (CONTINUED)

Page

Experiences in Growing, Processing and Marketing Guayule Rubber 150

Guayule and Its Incorporation As an Economic Enterprise by American Indians 160

Concluding Remarks 166

Participants 170

INTRODUCTORY REMARKS

William P. Miller
Special Projects Officer, Bureau of Indian Affairs

To speak to the distinguished scientific researchers, Indian tribal leaders and other participants of this guayule "Conference" is a great honor. This privilege carries with it a responsibility to make a few introductory remarks on the purpose, importance and why, now at this time of our economic/industrial history, we should make a modern technological assessment of this rubber-producing shrub and again consider it as a possible new crop for arid and semiarid regions.

Before doing this, I would like to express on behalf of the Department of the Interior, Bureau of Indian Affairs, our gratitude to those other Federal departments who have joined us in financially supporting this Conference and the follow-up study by the National Academy of Sciences. Specifically, we wish to thank Mr. Mort Baill, Director, Office of Technical Assistance, Economic Development Administration, Department of Commerce; Dr. George Blue Spruce, Director, Office of Native American Programs, Department of Health, Education and Welfare; and especially Mr. Paul A Vander Myde, Deputy Assistant Secretary, Department of Agriculture, and the Director, Agriculture Research Service, who have assisted us in evaluating the merits and scope of this first phase effort to conduct a modern technological assessment of the guayule plant. In general, we extend our special thanks to the University of Arizona who has done a superb job in hosting the Conference and researching and publishing a bibliography on guayule. In particular, we owe thanks to Dr. William McGinnies for his excellent work in directing the organization and conduct of the Conference.

Briefly stated, there are, among others, seven reasons which provide us with the rationale and justification to study guayule at this time. They are:

(1) Rubber is a strategically important material and the U.S. now depends on a natural rubber supply that is 10,000 miles from our shores. Since there are only a few rubber-producing nations, there is a monopolistic control over its supply from an area in the world which appears to be reassessing its political and military alliances. Therefore, guayule is worth investigating even if only to clarify its strategic implications.

(2) Related to its possible strategic importance is that the rubber-producing nations are openly considering setting up a rubber cartel. If this does occur, the U.S. and other user nations of natural rubber will be vulnerable to possible fluctuations in the price levels of rubber which would be influenced more by political and military rationals rather than purely economic ones.

(3) Primarily, because of the controls which the OPEC nations have on the existing supplies of our imported petroleum, President Ford has asked the nation to seek domestic alternatives to imported petroleum. Guayule may possibly be one. Its rubber is hydrocarbon, the same class of molecule that is in petroleum. Today it seems very important to study plants that produce hydrocarbons for the nation's industry.

(4) Natural rubber has retained a strong market and today it is very much in demand. It is now predicted that by 1980, 40% of all rubber sold will be natural

rubber. In the 1940's it was thought that man-made substitutes would so dominate the market that research on guayule was not justified. That may have been correct then; today, it might not be.

(5) In the 1940's gasoline sold for 20 cents or less. Today, it is between 55 and 68 cents. Synthetic rubbers are very seriously affected by the skyrocketing petroleum prices because they are made from petroleum feedstocks. This condition casts guayule economics in a new light today. In 1953, the ARS stopped guayule research because of economic and international political and trade considerations; now renewed research may be justifiable, even on economic grounds and in the light of the shifting international alliances which are now taking place in the Far East.

(6) In the last 30 years, there have been tremendous breakthroughs in science and technology: in plant genetics, in agricultural technology (such as pest control, weed control, mechanization, etc.), in chemical instrumentation, in chemical engineering, and in rubber technology. There are new techniques unknown at the time of the former guayule projects. Today, it may be possible to revolutionize guayule production to make the former projects appear like high school and college level experiments.

(7) The present economic development crisis on our Indian reservations demands that the BIA take every initiative possible to evaluate the feasibility of new business opportunities and to formulate projects which may have a high economic potential for significantly easing the high unemployment and under-employment rates (as high as 49% to 90% on reservations here in the Sonoran Desert region of the Southwest).

In the light of these reasons to hold this Conference and modern study of guayule, it is our hope that this effort to bring science and technology to bear on some of the critical economic development problems and issues which face this nation and the developing world will be particularly successful in turning recent research results into a usable and practical form so that the appropriate decision makers in government and the private sector can decide whether or not guayule has merit for consideration to be developed as a domestic source of natural rubber.

On behalf of the Department of Agriculture, Department of Commerce, Department of Health, Education and Welfare and Department of the Interior, I wish you success in your efforts to objectively assess the future potential of guayule.

Thank you.

GUAYULE PRODUCTION PRIOR TO WORLD WAR II

W.A. Droze
Texas Woman's University, Denton, Texas

Guayule, a shrub which resembles the sagebrush, grows wild in North-Central Mexico and nearby areas and in the Big Bend region of Southwestern Texas. The plant usually attains a height of two to three feet and has crooked, brittle branches. Its slender leaves are grayish-green, and it produces inconspicuous yellow flowers on short slender stems.

Guayule was "re-discovered" in 1852 by Doctor J.M. Biglow, M.D., while the doctor was a member of the Mexican Boundary Survey party. Biglow collected specimens of the plant growing near Escondido Creek in Texas and sent them to Professor Asa Gray of Harvard University. In 1859, Gray first described guayule scientifically and gave it its botanical name Parthenium argentatum.

Long before the scientists described the guayule plant in the mid-19th century, North American Indians had discovered that it contained rubber and that the rubber could be extracted by the mechanical process of chewing--a process not substantially different in principle from the pebble mill method of extraction. The rubber was gained by the communal mastication of the bark of the guayule plant.

According to a Spanish visitor to Central Mexico in 1510, 342 years before Dr. Biglow's discovery of the guayule plant, Aztec Indians "had a game which they played with balls made from the juice of a certain herb."[1] Although the Indians probably gained their rubber from guayule, it is also recognized that other plant sources of rubber were available to them.

Lloyd tells us of still another use of the guayule plant. He relates that because of the plant's resin content (which made it burn with a fierce, hot flame, like a pine knot) it was used to fuel the Mexican adobe smelters in mining areas of Northern Mexico. This means of utilization resulted in the depletion of "thousands of acres" of guayule.[2] The plant also fueled the bread ovens of Mexican women in the northern provinces of Mexico until it was established that the shrub had a more valuable use.

Known by the Indians for many centuries as a source of rubber, it was not until the last quarter of the 19th century that the demand for rubber directed attention to the guayule plant as a possible source of latex or caoutchoc. In 1876, the Society of Natural History of Mexico began to study the plant's potential as a source of rubber and, in conjunction with the State of Durango and the Mexican government, sent an exhibit of guayule rubber to the Philadelphia Centennial Exposition of that year. The Centennial Exhibit did not attract the immediate interest of American developers, and presumably the shrub received no further attention other than that of the playfully-inclined Indians, or that which it received regarding its other non-rubber uses.

Commercial exploitation of guayule began in 1888. In that year, John Cheever of the New York Belting and Packing Company sent an agent to Mexico to procure a quantity of "guayule bark." Apparently, the firm believed the latex to be contained only in the bark portion of the shrub. Much to the dismay of his supervisors, the agent sent back to New Jersey 100,000 pounds of bark, stem, leaves and all. The freight bill on so much useless woody by-product discouraged further importation. The firm made the best of what was considered a bad situation by stripping the bark

from the plant, boiling it, and extracting whatever rubber remained. Freight and labor costs made for an extremely expensive product but the quality of the rubber produced was regarded as excellent.[3]

The 1888 venture demonstrated that the guayule shrub provided quality rubber but at great expense. About the same time, English and German scientists began to explore the potential value of guayule rubber. The first German contact with the shrub was not exciting. The rubber, sent to Germany, was produced by the chewing of the bark by Mexican natives. The German chemist reported that guayule rubber had no future commercial value.[4] The advocates of guayule refused to give up, and other shipments were sent to German chemists for processing. By 1900, Hamburg entrepreneurs were marketing small amounts of guayule rubber which had been obtained by treating the plant with caustic soda, or dissolving the rubber from the plant. The year before, an Italian scientist, William Prampolini, had patented a method of extracting the rubber by using solvents. Prampolini revealed his method to American promoters Thomas F. Ryan and Senator Nelson W. Aldrich, who shall receive more attention anon. The solvent method of extraction, though expensive, awakened the Mexican government to the commercial value of the guayule shrub. A tax of 15 pesos per ton was imposed on guayule exports which brought the extraction phase of rubber manufacture to the guayule fields of Mexico.

The first Mexican guayule factory was established by German capital at Jimulco, Mexico, in 1902. It employed a solvent process of extraction. Although chemical extraction was costly, the Compani Explotadora de Caucho Mexicano began marketing its product in 1905. The future of the firm's efforts would soon be doomed by Yankee ingenuity. The solvent method used by the company was too expensive and yielded too little of the plant's latex. A better method of separating the rubber from its woody prison was imperative if the guayule industry were to prosper.

An American, William A. Lawrence--forty years a chemist--whose firm had been extracting hops by means of gasoline, developed a mechanical method of extraction which eventually replaced the solvent method. E.B. Aldrich, a financier and promoter who was interested in developing guayule rubber, believed that the extraction process which utilized gasoline might be adapted to rubber production from guayule.

Lawrence took six months to prove that the gasoline extraction process was unworkable. He concluded that one should try to get the wood out of rubber instead of getting the rubber out of the wood. An alkali process was tried first. Although unsatisfactory, Lawrence observed that when the shrub was ground in the presence of water, a fiber rubber was formed. Howard and Ralph Wolf described Lawrence's methods accordingly:

> Working in a temporary laboratory at his home in Jamaica, Long Island, with the assistance of his chemist daughter, Clara Louise, he ground up some dried shrub in the household coffee mill, and rolled it in a glass fruit jar with water and a handful of pebbles. Rubbing and pressure in the presence of water described the process in the patent which he *[Lawrence]* took out in 1903.[5]

Lawrence's extraction procedure was so promising that he and promoter Aldrich immediately went to the guayule-producing region of Mexico to determine the availability of the shrub for processing. Assured by their visit that an adequate supply was obtainable, Aldrich and Lawrence established a small extraction factory using "a regulation size pebble mill" in New York. The first production by the new

process was sold to the Manhattan Rubber Company in 1904. Possibly because of freight expenses and Mexican import taxes, the guayule extraction process was forced to return to the source of the shrub. Aldrich and Lawrence established a small factory at Torreon, Coahuila, Mexico, in 1904; and the truly successful "commercial extraction and processing of guayule rubber" was initiated.[6] In the same year, E. Delafond, a French chemist, discovered that "when pulverized guayule was treated under pressure, the woody fibre became water logged and separated from the rubber."[7] Delafond's patent was later purchased by the successor of the Aldrich-Lawrence enterprise. The small mill at Torreon proved very successful, and it shipped 50 pounds of crude rubber to the United States late in 1904.[8]

The success of the small mill led to larger ventures. American ingenuity and initiative were joined by American capital. In January, 1906, the Continental Rubber Company was formed with a capital of $30,000,000 to exploit more fully the Lawrence and Delafond patents. E.B. Aldrich was the president and William Lawrence was vice president. Other major shareholders were Thomas F. Ryan, Senator Nelson W. Aldrich, Bernard M. Baruch, Meyer Guggenheim and John D. Rockefeller Jr. Later, two subsidiary companies were formed--one to concentrate on developing a supply of guayule through the purchase of a vast tract of land in the heart of the guayule country of Northern Mexico, and the Continental-Mexican Rubber Company which would build a larger mill at Torreon, modeled after the smaller factory built in 1904. The new facility had a capability of producing 12,000,000 pounds of wet rubber annually.[9]

The success of Continental Rubber Company spawned competitive ventures. Extraction plants were established at San Luis Potosi, Saltillo, Monterrey Gomez Palacio, and Jimulco in Mexico and at Marathon, Texas by the Texas Rubber Company (formerly the Big Bend Rubber Company) to use the native guayule of the Big Bend Country.

The Madero brothers, Francisco and Gustavo, who acquired a huge area of wild guayule and developed eight factories to process the shrub, were the largest competitor of Continental Rubber. Guayule rubber made Francisco Madero wealthy and made possible his successful revolution of 1911 which, in turn, made him president of Mexico for a season. Madero's financial success in exploiting 2,000,000 acres of the guayule plant made it difficult for him to maintain his image as an advocate of the landless Mexican peon.

The rapid expansion of the guayule rubber extraction industry in Lloyd's words "soon became a matter of moment to determine the relation of supply of the shrub to the manufacture...."[10] An early estimate determined that the total supply of the plant in Mexico was 375,000 tons. Between 1888 and 1911 the rapid harvesting of guayule had consumed approximately 60 percent of the then available native guayule.[11] Lloyd's calculations gave a more optimistic projection of the available supply, but he concluded in his report of 1911 that "the total amount of virgin shrub is sufficient to last no more than four to six years at the present rate of consumption."[12] Concern over the use of the plant was indeed warranted, for between 1906 and 1912 the world's rubber supply was increased by 128,000,000 pounds of guayule rubber, a rate of production which nearly equalled the rubber output of plantation Hevea for the same period! Had not the Madero Revolution of 1911 intervened and closed the guayule factories, it is almost certain that the plant would have become extinct in Mexico. Aiding the course of destruction was the increasing price that land owners obtained for guayule which rose from $7.50 to $50 per ton by 1911. For Continental Rubber, which had invested about $30,000,000 in guayule facilities, and which took over the Madero Company in 1911 and was reorganized as the Intercontinental Rubber Company, it was clear what had to be done. It was obvious to guayule processors

that domestication and cultivation of the plant was mandatory if the industry were to survive.

Foreseeing the fate of native guayule led the Continental Company to undertake experiments in the cultivation of the plant in 1907 at its Cedros ranch. In 1908, German rubber interests also initiated a program of planting in East Africa. These early efforts produced few results. Lloyd, writing in 1911, four years after the Continental Company began its trials, devoted only two short paragraphs to the subject of guayule cultivation, a situation which is indicative of the progress which had been made in the ensuing four years.[13] The Mexican government also recognized the need to conserve this valuable resource and initiated a policy which prohibited the harvesting of guayule plants "when diameter at the ground line was smaller than a man's thumb."[14] When the price of guayule reached $50 per ton, the Mexican peon's thumb grew very small! Sustained yield Mexican-style was obviously not the answer.

The seriousness of the problem was made more dramatic by the closing of several processing plants because guayule supplies were unavailable. In 1910, Continental Rubber renewed its efforts to cultivate the shrub. At that time, Dr. W.B. McCallum, a young but talented botanist, was employed by Continental Rubber and sent to the firm's Torreon, Mexico ranch to direct experiments in cultivating guayule. The company had previously engaged Professor Francis Lloyd of Alabama Polytechnic Institute (Auburn University) to study the plant. Lloyd's report, published in 1911 under the title Guayule--A Rubber Plant of Chihuahuan Desert, is still a valuable textbook for studying the plant. McCallum began his work in 1910 and after seventeen years of trial and error, but patient devotion to his goal, succeeded in "transferring the plant from its wild home to cultivated fields." McCallum saved the guayule industry from extinction, but his achievement was not accomplished in easy fashion.

McCallum immediately faced two rebellions. One was that of the guayule shrub which resisted civilized growing. Cuttings were planted but few took root. Seed collections produced largely chaff. Moreover, the minute wild guayule seeds were frequently barren or only partially developed. One of the first tasks was to develop plants with full seed vessels. While these experiments were being conducted, Northern Mexico fell victim to prolonged civil strife and ultimately revolution and civil war. Both the factories and the experiments had to be abandoned.

In 1912, McCallum was instructed to gather a seed supply and to move his cultural operations to the United States. The Mexican government refused to allow McCallum to carry guayule seeds from the country. According to Ken Taylor, Dr. McCallum hid his seeds in a tobacco tin which Pancho Villa's border guards ignored when McCallum was searched at the border.[15] Four hundred acres of land near San Diego were purchased in 1912 to begin cultural operations. Time does not permit the cataloging of all of the trials and tribulations that Dr. McCallum underwent to get the seedlings to grow, to speed up the plant's growth, and to grow a plant that would maintain a consistently acceptable level of latex content. I will mention only a few.

Rapid plant growth and plenty of rubber content became the twin goals of the botanist. Plots of guayule were planted throughout the Southwest in order to produce plants that would fulfill these objectives. Arizona was the recipient of one such plot, and McCallum moved his base from California to a location just south of here. Arizona plants were no more suitable than those produced near San Diego--low rubber content was the minus factor. McCallum's test plots results eventually led him to the Salinas Valley of California, which appeared to have the most suitable climate and soil and the most available land for producing shrubs with an

acceptable amount of latex. In 1925, Salinas, California, was made the center of Intercontinental Rubber's cultural operations; and during the next several years some 8,000 acres of guayule were planted in the Salinas Valley. Contracts were made with valley farmers to grow the shrub.

Early in 1931, even though depression stalked the land and rubber prices followed the downward spiral of the business curve, American Rubber Producers, a subsidiary of Intercontinental Rubber Company, built a $150,000 extraction factory in Salinas. Modeled after the mill at Torreon, Mexico, the new plant could handle the output of 7,000 acres of machine-produced guayule. During the next decade, 3,068,630 pounds of guayule rubber were produced by the Salinas factory or about 700 pounds for each acre harvested. If 1925 prices of $1.23 per pound had continued into the 1930's, the mill would have been a gold mine. However, cartel controlled prices were terminated in the 1930's and the price of rubber fell to a low of three cents per pound. In 1933, guayule growing and processing became unprofitable. Valley farmers who had contracted to produce guayule for Intercontinental plowed or burned their fields and turned to irrigated crops.[16]

Depressed rubber prices led company officials to seek government aid. Washington was approached on the basis that an independent source of guayule would be a valuable asset to the nation's security. The effort was successful in gaining governmental interest, for early in 1930 Majors Gilbert Van B. Wilkes and Dwight D. Eisenhower arrived in Salinas to study guayule as a rubber source. In June, 1930, the officers reported very favorably on the possible utilization of guayule rubber if foreign sources were unavailable. Interestingly, the report pointed out that the growing and manufacture of guayule could give "profitable employment to some thousands of American farmers, mechanics, and laborers."[17] Majors Wilkes and Eisenhower recommended a program of governmental purchase of 30 cents per pound to assure a source of domestically produced rubber. The proposed price appears quite satisfactory since the firm computed their production cost at 13.26 cents per pound. The report also pointed out that a domestic supply would give protection to American consumers from Far Eastern cartels' controlled prices.

The report had little, if any, impact on the Hoover Administration, which was being besieged by far more powerful economic groups--also victims of depression--in search of governmental support. Intercontinental Rubber was left to its own devices. Prices continued low throughout the 1930's but a gradual incline began after 1933. By 1941 plantation rubber prices in the New York market reached 22-1/2 cents per pound. The price rise kept Intercontinental in business and Dr. McCallum at work on producing better seeds.

As the Far Eastern power balance began to change in the mid-1930's, guayule was destined to have a more important place in the nation's defense posture. By 1939, Japan's military successes in China and its potential threat to the rubber plantations of Southeast Asia further enhanced governmental interest in guayule as a protected source of rubber. On June 12, 1941, Representative John Z. Anderson of California introduced a bill in Congress which provided for the federal government to take over the facilities of the Intercontinental Rubber Company, but the bill was not passed. After Pearl Harbor, in December, 1941, with the Japanese in control of the Hevea plantations in Southeast Asia and synthetic rubber manufacture still an infant industry, and facing a critical shortage of rubber, Congress in March, 1942, directed the Department of Agriculture to purchase the buildings of Intercontinental Rubber and initially to plant 75,000 acres of guayule for rubber extraction. A month later, President Roosevelt allocated $884,000 to the Emergency Rubber Project; and on February 10, 1942, Major Evan W. Kelley arrived at Salinas.

Kelley's associate, Paul Roberts of the Forest Service, former director of the Great Plains Prairie States Forestry Project and an expert in the administration of emergency projects, along with Henry Lobenstein, John Emerson, and other former "Plains Shelterbelt" personnel joined the project on February 15, 1942.[18] Soon thereafter many of you here this morning found your way to Salinas from the shelterbelts of the prairie-plains or from the Service's regional offices. Guayule culture, rubber extraction, and a myriad of other tasks were begun on an emergency basis and in an escalating fashion. The "Breakfast Conference" presided over by Kelley and Roberts made it all work.[19] In a matter of months the nation had developed an independent source and a small supply of natural rubber.

NOTES

1. W. Gordon Whaley, "Rubber--The Primary Source for American Production," Economic Botany II, (April, 1948), 199.
2. Francis E. Lloyd, Guayule: A Rubber Plant of the Chihuahuan Desert (Washington, 1911), 6.
3. Edgar L. Perry, "Growing Rubber in California," Journal of Forestry, XLII (May, 1944), 324.
4. Lloyd, Guayule, 7.
5. Howard Wolf and Ralph Wolf, Rubber: A Story of Glory and Greed (New York, 1936) 274.
6. The Wolfs date the founding of this mill as 1905, p. 274.
7. Howard Wolf and Ralph Wolf, Rubber, 274.
8. Lloyd, Guayule, 8.
9. United States Department of Agriculture, Forest Service, Final Report: The Emergency Rubber Project (Washington, 1946), 10, compiled by Paul H. Roberts.
10. Lloyd, Guayule, 10.
11. Ibid., 11.
12. Ibid.
13. Lloyd, Guayule, 12.
14. Kenneth W. Taylor, "Guayule--American Source of Rubber," Economic Botany, V (July, 1951), 257.
15. Ibid., 258.
16. Ibid., 258-9.
17. USDA, Forest Service, Final Report: The Emergency Rubber Project, 13.
18. Interview with John Emerson, former Nursery Supervisor, Emergency Rubber Project, Tucson, Arizona, November 17, 1975.
19. Perry, "Growing Rubber in California," 325-331.

ILLUSTRATED REVIEW - EMERGENCY RUBBER PROJECT*

W.A. Campbell
Plant Pathology and Indicator Plots, Emergency Rubber Project

*It was impossible to include slides in the proceedings, but it was believed that this shortened version of Dr. Campbell's talk should be included as it does contain a great deal of useful information on the Emergency Rubber Project.

I am going to show you a group of slides which were put together at Salinas, California, at the end of 1943, and which were used at Washington at the Congressional Hearing for the appropriation for the 1944 fiscal year. Most of these slides were taken with an old Argus CC camera, which would be rather primitive when compared with today's photographic equipment. This group of slides came back to me in a nice little wooden box after they were used in Washington, and I have kept them ever since. Just within the last three or four months I have been trying to find out what to do with my old guayule relics. I was trying to find some hope for them, and I think I am going to leave them now with the University of Arizona. They seem to be more interested in guayule here than anywhere else. What you are going to see will be the operation of the guayule project during 1942 and 1943.

Perhaps in this first slide you will recognize Dr. Lloyd, who was the man who wrote the monograph on guayule. Dr. Lloyd came to this project early and I believe that he died before its termination. But this is Dr. Lloyd as he was when he visited Salinas about 1942 and I was fortunate enough to get this picture of him.

This slide shows Dr. McCallum, and those who were on the old project say this is a very good likeness of him. This is Dr. McCallum as he appeared to most of us, but in this particular photograph he is not wearing his black overcoat, which he says that he acquired when he first moved to Salinas. He wore it summer and winter from that time on. I think his son, who is here in the audience, perhaps appreciates the remark about the overcoat because it was a real necessity. You never knew when you had summer or winter in Salinas.

This slide shows the Intercontinental Nursery at Salinas as it was in 1942. As you can see, it is about 20 acres of nursery with buildings in the back and the duckboards on which the carts are running. These were considered necessary in order to keep the machinery from miring in the mud at Salinas and at this particular nursery site there was a wethole. In the winter time it would get very wet and if they did not have these duckboards, their equipment would sink in the mud.

Here you have the largest and oldest of the plantings of the Intercontinental Rubber Company as it was when we arrived on the scene. This shows the older shrubs which have completely filled the bed. Here is Dr. McCallum and you can see from his knees how high the shrubs were. It probably was a warm day because he does not have his black overcoat on. This shows the shrub which we are getting ready probably for processing, assuming we could get a large enough crew to work on it.

This is the processing mill at Salinas which shows the general appearance of the plant. These are the pebbles which came, I believe, from Denmark because they didn't have any of the right kind at Pebble Beach, or wherever they had pebbles. These pebbles were an important part in the milling process.

Here are the nursery beds, machinery to develop and plant them, lay the seed down, cover it with a very uniform layer of sand, and in this particular slide

which was taken after 1942, it shows that we have no duckboard. What happened was that when we took over the secrets of the Intercontinental Rubber Company we had to use their secrets. And one of the secrets was the duckboard in the nursery bed, and in the dryer nursery sites we used them until they were not needed. They proved to be a hazard because the ends of the planks would curl up and instead of the wheels going over them they came up over the wheels.

Weeds almost took over the project, as this slide shows, about March or April near Salinas. During the first year the weeds came up faster than the guayule. If it hadn't been for about 6,000 women, mainly from around Salinas, the project would have ended in a weed patch. This shows the weeds and the number of weeders. This whole process, or this ordeal, showed the strength or the durability of the guayule as a cultivated crop because, despite all the problems of the weeds and everything that went with it, guayule came through. I believe it is one of the easiest handled crops when given attention. This shows a typical cart with the folks running up and down the bed. One of the nurserymen, Milt Andrews, came across one of these cartoons, a Goldberg cartoon, in which a guy lays on his stomach on a cart and goes up and down the bed to see the weeds. He figures this is just about that sort of thing. Competition existed between the weeding crews and it got to be a problem sometimes because they would compete to the hair-pulling stage.

They developed the weed control with stove oil and this shows how the weeds were controlled after the first year. This was absolutely effective and was probably one of the biggest advances they had in guayule culture. This same sort of thing was used later in forestry nurseries, using mineral spirits, but in this particular case it was stove oil and was a technique that was used on carrots. You may remember at one time that carrots all tasted like kerosene--that's because stove oil was used to control the weeds.

This is a nursery in the middle of summer. Guayule is a beautiful plant--an easy one to grow in a sense--because all that was needed was a little space and a little water, and it took off. But if you had hay fever, keep out of it.

This is the cultivating crew which ran a tractor which had a cultivator with a bar that could be moved back and forth to go between the rows. One thing about guayule is that it cannot be transplanted with the top on. There are several theories as to why. One which has been worked on is the thought there might be auxins involved which would inhibit the formation of fruit. Daley Felice, I believe, put that idea to rest, in my mind, because all he did was to transplant guayule with tops on and put a lamp chimney over them so there would be no transpiration. Of course the plants would grow whether they had the tops or not. If the tops were left on, water was transpired out in a hurry and the plant would die, so they had to be topped. This particular topping machine has a little history. Some of the folks who were around the administrative end may recall that International Harvester was given the job of rigging up three machines, and we were surprised at the bill. The bill for each of the three machines, I believe, came to around $10,000. The machines seemed to be rather expensive; considering all the engineering involved, it's probably reasonable.

The next stage is the lifting, and here is a regular nursery lifter which goes under and cuts the roots and loosens the plant. This shows how the plants had to be handled, separated, graded and packed. This is an early crop before things were mechanized a little bit more; it shows the amount of hand labor involved at the time. They took stacks and stacks of lettuce boxes, standard lettuce crates used in the Salinas Valley. They proved to be suitable for guayule. Then bales of redwood bark were used as packing material. There had been a lot of trouble in storing

guayule seedlings because they would rot in storage and this is the crate that was developed so that it could be kept in cold storage almost as much as a year without too much deterioration. The main problem was with moisture particularly from condensation. This particular pack proved to be suitable for both storage and for field handling.

It took a while to perfect a planting device. First they used a regular celery planter which was a little bit complicated. This happened to be one of the earlier planting machines; it shows a group of folks that were trying to keep their fingers out of the guayule to keep from being planted themselves.

Here is one of the planting crews in the fields. This happens to be Salinas and you can see where the guayule has been planted rather evenly if the ground is prepared without too many lumps in it. Several other experimental machines were used.

A lot of field cultivating had to be done. This shows one of the weeding crews. At one time we had German prisoners at one of these camps who did a lot of this work. But this is one of the Mexican nationalist groups at work. Field plantings would grow rapidly under the proper conditions, and to me it was one of the most successful types of plants that could be grown. In the wintertime the plants were without inflorescences and had a gray appearance. It was during the winter that the plants would accumulate rubber so that this dormant period with moisture and lower temperatures was very important.

Seed was one of the problems. Seed that the old Intercontinental Rubber Company had was rather limited. And we couldn't begin to plant the 30,000 acres that we thought we were going to plant--and the 75,000 acres that was later planned--so during the first year of the Project it was important that we gather seed.

Here is one of the labor-saving devices that was used to try to get seed from very small plants and there is a group of seed gatherers, trying to get a few seeds together. This slide of the nursery shows that seed is produced in the nursery plant very early. The winter crop has a heavy production of seed just before it begins to grow in the Spring. One device was worked out by the shopmen at Salinas in order to brush seed off from the nursery plant. At the end of the row they would stop and gather the seed onto the canvas and continue down the next row. Later on, Jim Byrne had developed more efficient and larger seed-gathering equipment.

They were so anxious for rubber that they went to the Big Bend area of Texas and gathered up shrubs from there and shipped them to Salinas for milling. This shows a boxcar of the baled shrubs that came from the 0-2 ranch in Texas. They were relatively large shrubs, rather limited in amount, but quite a bit of rubber was obtained which proved to be very important because it came at a time when natural rubber was getting low. I believe that the rubber was needed for gas tanks on aircraft. It came in handy because it was a soft type of rubber useful for that purpose. We had indicator plots in many areas and this shows Harold Reynolds in one of the plots. Indicator plots were located in small areas and the main purpose was to see where guayule would grow; it would grow almost anywhere. A couple of hundred plots were located from Texas to Northern California. The nursery at Indio had an interesting growth pattern. Seedling establishment was erratic. The area had high temperature and sandy soil which had to be irrigated abundantly. The plants would group themselves like many desert plants, so occasionally one would take hold and grow. No matter how much water was supplied, some of the plants would not grow.

I sent to Washington to the Archives to see if they had any kodachromes of the guayule project. They said they would make a search which would take six weeks. They took six weeks and gained two slides, for which they charged $1.25 each. They also sent a list of records which indicated slides but the stamp on most of them said, "Nothing here; nobody home; had been borrowed and not returned."

This slide shows a planting at Shasta, California, in 1944, one of the few plantings at Shasta. It shows guayule will grow under irrigated conditions. A processing mill was built at Bakersfield to handle the shrubs and there would have been a considerable volume to process had the project been carried through.

The folks who were working on the guayule project during the war years were really dedicated to what they were doing, and they really believed they were contributing to the war effort. The unhappy part was to think that we had 30,000 acres planted that could have been harvested but were not harvested. I felt that when the fields at Salinas were destroyed (I have pictures of the burning shrubs) it was a sad commentary on our short-sightedness at the time that we did not try to do something with the guayule that we had on hand.

Questions for W.A. Campbell

Question: (Joel Schechter) How old was the planting in the last picture? Do you have any figures on yield and what was the rainfall at Salinas during that period?

Answer: (Campbell) The planting was three years old. As to rainfall, that was one of the things that we tried to follow very closely during the time we were at Salinas in order to try to predict what we could get from one year to another. I had a rainfall chart in my office which started off in one corner and came around for about a year. We were sure of one thing and that was that rainfall next year would not be like it was this year. And I believe the first year we were there the rainfall was relatively high. It was about 25-26 inches. Before we were through it had dropped down considerably to 15 or 16 inches but I believe the average rainfall is perhaps about 18 to 20 inches. The first year was very wet and that just about ruined us in the nursery.

Comment: (Henry Lobenstein) About the rainfall in Salinas, you have to remember this. Salinas is just a few miles from the coast; the rainfall right at Salinas where the old company mills were was up in the low 20's. Down the valley 15 miles the average annual rainfall was around 16-17 inches because we got away from the coastal influence very rapidly with many more days of sunshine because we were away from the coastal fog. So when you talk about rainfall at Salinas you have to talk about whether you are downtown or whether you are 15 miles up the valley. John Emerson and I were just talking; the question was asked about the rainfall at Bakersfield. As I remember, it was around eight inches annually with some variation. The upper end of the Sacramento Valley around Chico is again up to around 12-13 inches of rain.

Let me come back to the question of yield and some of you can bear me out on that. In my mind as I remember it, we figured that if you got one ton of rubber per acre per year over a four-year period or four tons at the end of four years, you were doing pretty good. That is what we'd expect to get. At Salinas it was one ton because that was the better acreage. I believe some of the indicator plot data will indicate what you would get at the end of one or two years.

Comment: (Sidney Kalver) I was in the pilot plant and I have a blurb from the Chamber of Commerce of Salinas that was written to the Christian Science Monitor

in 1944. It indicates that you can get from 800 to 1600 pounds of rubber per acre in two years without irrigating; and with irrigation you can materially increase that production; whether or not at less cost than without irrigation has not been fully determined.

Comment: (Henry Lobenstein) I'd like to add to that. One must remember that the rubber production per acre varies tremendously according to whether it was dry land or irrigated land and age of the plant. For example, when the government bought the Intercontinental Rubber Company holdings, the Spence field was 11 years old and was then nonirrigated for 11 years. It ran slightly over 22 percent rubber. On the other hand, at Bakersfield where we irrigated, two-year-old plantations would have a rubber percentage of less than three percent. Even under irrigation, as the plant became four years old, that percentage in that particular field might have tripled, and I'm talking about percentage per pound of dry weight. It seemed to us the older the plant got, up to an age of perhaps six or seven or eight years, as soon as it reached maximum size the percentage of rubber increased gradually at an increasing rate as the plant got older. In other words, as the texture of the plant became less succulent, the percentage content of rubber increased.

I was recalling from memory the Bakersfield area. When the rubber percent increased to about 10 percent, this was about the limit that it ever got because the shrub growth kept pace with the increase in rubber. It held at that constant percentage level but the yield increased markedly year after year because of shrub growth.

POST-WORLD WAR II GUAYULE ACTIVITIES

Leslie Baird
Free-lance Writer

To a large extent, what happened to the guayule shrub and guayule rubber after the end of World War II was the result of the momentum of policies and projects started and developed during the war. There were still emergency-motivated projects. Once the emergency had lapsed into the limbo of history, interest slackened or shifted. I'd like to make one deviation at this point. I feel that practically everyone that I contacted one way or another during the process of the research always referred to emergency rubber, emergency this, emergency that. Well, this is true; it was! But after all, it had been harvested and processed in Mexico and to some extent in California before, and it wasn't emergency rubber then.

The rubber industry, which had been glad to get any kind of rubber during the shortage, looked with favor on newly developed synthetic quality specialty rubber, as well as the lower grades which were produced for a cost of approximately $650,000,000. Compare this with the gross cost of $45,000,000 spent on guayule during the Emergency Rubber Project.

After the Congressional Recession Bills in 1945, which decreed the end of the Emergency Rubber Project at Salinas, California, the Spence Mill was closed on December 14, 1945 and the Bakersfield Mill on December 9, although the project was given a reprieve of six months to liquidate its assets.

Some 900 acres of growing guayule shrubs near Salinas were spared the hell-bent-for-normalcy drive, together with a 1,062-acre ranch near Beaumont on the road

to Palm Springs in Riverside County. There are also other plots of small size which were spared and I understand there were some in the Oceanside area which is now Camp Pendleton. There may be others too.

That left about 23,000 acres to be destroyed. Yet wartime controls on rubber remained in effect. Meanwhile, the U.S. rubber authorities began to stockpile Hevea from Southeast Asia. It was fortunate that the Southeast Asia rubber plantations hadn't been damaged to the extent expected by the retreating Japanese armies.

During this hiatus of guayule liquidation, $10,000,000 worth of what could have been processed into guayule rubber either went up in smoke or was disced under as fertilizer, as Bill Campbell mentioned earlier.

Thus the Emergency Rubber Project came out with a net cost of about $37,000,000 and a lot of scientific papers on guayule--how to grow it, extract it, process it and countless other technical aspects.

To digress a bit, it is ironic that while the war-motivated research and production of guayule greatly advanced the art and knowledge of every aspect of the shrub, our myopic action at the close of the war killed guayule. And remember that the Emergency Rubber Project had purchased a going guayule facility together with several hundreds of acres of shrub.

I am cognizant that Intercontinental Rubber wasn't interested in taking it back (they seemed to have lacked something) because it probably could have been reacquired as surplus for a few cents on the dollar like so many other war-induced plants, including the synthetic rubber facilities.

During the war, a California State Committee on Guayule had been set up by the Legislature under the direction of Governor Earl Warren. The committee was made up of farmers owning and controlling large farming tracts up and down the State with the overall purpose of continuing, if possible, guayule cultivation after the war. Aside from using the committee as a forum for gripes against the war project, such as the wages paid by the government to the workers in the field, few of them voted to continue guayule on their land, so eager were they to get back to food crops. Had the government kept one of the mills open and gradually harvested the existing fields one by one, the history of guayule might have been changed from a dead dodo-bird to something alive.

One man, however, who is scheduled to speak to you in this Conference, managed to stave off the destruction of the aforementioned Grand View Ranch. Mr. Hugh H. Anderson, who had familiarized himself with guayule with the group of CalTech scientists who assisted the interned Japanese at the Manzanar Camp, developed what was known as the "Little Guayule Project" and organized a company called the Desert Rubber Company.

With much difficulty because of wartime controls, he and his associates were able to obtain an agreement with the rubber authorities to allow them to sell their product after they had built a mill--not for tires which were still being rationed--but of all things, chewing gum!

Suffice it to say, when the mill was finally built and some shrubs were harvested at Beaumont, the Wrigley Company had located a much cheaper source of rubber and the deal was off. Desert Rubber Co. did not have the finances to mark time until the controls were lifted. So much for the first post-war effort to keep guayule alive.

Of course rubber production in Parthenium argentatum continued in Northern Mexico after the war. For forty or so years, the Intercontinental Rubber Company harvested the wild shrubs over the northern states and processed them in several mills, the largest located in Torreón, Coahuila, which has been visited by many of you guayule experts. This company, however, had never been able to match the wild growth with successful domestication in Mexico.

During the latter part of the war, Intercontinental laid out a large plantation at a place known as Catagena. I've also heard it spoken of as Catagena Laguna; I think probably because it was planted on an old lake bed. This was located 60 miles north and a bit to the east of Torreón. Photos of the stand of guayule appear to indicate healthy plants but my guess is that the rubber content--for whatever reason--fell below a marketable level. So a million or so dollars were lost in its abandonment. Doubtless the Mexican Commission that has been studying guayule for the last three years in preparation for the reestablishment of the guayule industry there has analyzed the reasons for the ill-fated Catagena results.

In 1952, Intercontinental closed down all its operations in Mexico and in the following year merged or sold, whichever you prefer, to Texas Instruments of Dallas. I might say parenthetically, I think in spite of the fact that the guayule plant had a lot of value in Texas, Intercontinental had a listing on the New York Stock Exchange in Texas.

One can surmise that the reasons for closure included the competition with synthetic rubber, higher costs in harvesting and transporting shrubs to the mills, and the market price of rubber itself, although rubber costs usually went up and down like a yo-yo.

The recent work by the Comisión Nacional de las Zonas Aridas will probably be described by the representative on this panel from Mexico who will speak tomorrow. It seems to me that this action by Mexico bodes well for the future of guayule rubber in every respect and for all those interested in its reestablishment as the second source of viable natural rubber.

Going overseas (and I do not wish to steal any thunder from whoever is going to talk about other countries on the program) there was activity in the U.S.S.R. prior to World War II as evidenced by references in Blanchard's bibliography, although I have never encountered any printed material of a historical nature that mentioned extraction or processing. Everything was about the plant studies.

Mel Learner, the editor of Rubber Age, in a letter to me in 1961, wrote that Russia continued to experiment with guayule on a large scale and that frequent references appeared in rubber literature, but I have failed to find them.

My own efforts over a year or so to elicit a reply directly from Russian authorities finally ended in a blunt statement that guayule was no longer being cultivated in that country. Perhaps if detente is real that misty page of guayule history may be revealed.

Some 2500 acres of guayule were reported to be under cultivation in Turkey in 1949. I am not certain about the date. Mr. Anderson visited that country so perhaps he may fill in on that part of the history later on. Experiments with guayule and other rubber producers began during the war and continued into the post-war period for a while and then closed down. As I recall, there was some cooperation between the U.S. Government and Argentina in this regard. Harry Boucher, a chemist and specialist in deresination techniques, spent some time in Argentina for the

government and incidentally produced, gave me, or loaned me, quite a large volume called Memoria. This is of course in Spanish, telling about all of Argentina rubber works and it was quite voluminous but not quite as large as the E.R.P. report. I found the same thing with a book on the work in Spain which Ken Taylor was kind enough to loan me. I had never heard of either of these things before and I think this is part of our problem. In gathering all this material together we must be sure to have some source or media to bring it all together.

During World War II, considerable interest in guayule was generated in Australia for the possibility of producing rubber from plants other than Hevea. Test sowings of the Russian kok-saghyz dandelion were made as well as guayule under the auspices of the Commonwealth Scientific and Industrial Research Organization.

Several experimental acres were grown to maturity in an irrigated area near Barmera in South Australia. I am not sure of the date on that. According to the E.R.P. report, the rubber content of the shrub was determined by samples taken in 1949 of five years' growth. So I take it those were planted around 1943 or 1944.

Twenty-five plants of the same age were harvested from the Salinas/Spence field and milled for control. I think this is interesting because it is the only case I know where they compare foreign and domestic guayule. There was a marked difference in the size of the Australian guayule plants compared to the American grown types. The Australian plants averaged 24 inches in height from the first lateral root to the base of the flower stems. The Spence grown shrub averaged 17 inches. Dry weight of the Australian was 3.29 lbs. compared to the Spence selection of 0.80 lbs. defoliated. During the milling, the Australian sample gave off the pungent odor of turpentine and its resin amounted to 8.99% and rubber hydrocarbon 9.96%. The Spence shrub resulted in 7.88% resin and 12.7% rubber hydrocarbon. Extrapolating on a field basis, the Australian guayule would have yielded an estimated 2,259 lbs/acre to the 1,077 lbs/acre on the Spence guayule.

Here again I do not wish to poach on someone else's subject since Mr. Anderson knows a great deal about Australian guayule, having been employed for a time as a planner and consultant. Nevertheless, the project which he started near Perth was not cared for as he had instructed them. When he returned over two years later, he found a very uneven growth of shrub, the best of which tested about 10% rubber hydrocarbon. He told me that differences between the philosophies of the two leading Australian political parties entered into the project's picture and caused it to be shelved.

Thus I have mentioned--if briefly--the post-war guayule activity in Mexico, Australia, Turkey, the Soviet Union, and Argentina. I believe that with the exception of Mexico all these countries managed to grow commercially suitable shrubs. With the presence of a representative from Israel I discern that there has also been activity there. This is not altogether new to me but I have had no details. I must therefore leave the subject to Mr. Schechter of the Ben Gurion University of the Negev.

Some sort of negotiations were held with the Government of South Korea on the subject of guayule. Whether those talks got beyond the discussion stage, I do not know. The person who might fill you in on that is either Dr. Omer Kelley or perhaps Mr. Hugh Anderson.

That leaves us with two post-war projects in the U.S.: the seed program in the States of California and Texas in 1950-51 and the Natural Rubber Extraction and Processing Investigations in Salinas from 1948 to 1953. Associated with the Salinas Investigations, the Bureau of Plant, Industry, Soils and Agricultural Engineering

was also involved in research which continued until 1959. Nor should I omit the Stanford Research Institute study of 1947 which I will deal with later on.

Just why it was the Munitions Board that made the request for a stockpile of guayule seed from California and Texas in December, 1950, doesn't appear in any literature I've seen on the subject. Perhaps the undeclared Korean non-war had something to do with it. But there must be some kind of official explanation.

Nevertheless, overall supervision of the seed project was given the U.S.D.A. which assigned the Production and Marketing Administration of the Bureau of Plant, Industry, Soils and Agricultural Engineering to act in a technical guidance capacity. At least the government still considered the rubber orphan of the wastelands worth keeping on the back burner.

"The stockpiling project," says the U.S.D.A. Tech Bulletin #1327 on page 5, "was directed along two channels. In California the Bureau initiated a stockpiling program by transplanting available seedlings to 337 acres of land in the Salinas Valley for seed production. In Texas, under the technical guidance of the Bureau, nurseries totaling 529 acres were established to produce seedlings for possible use in a production program."

Unfortunately, I am unable to give you any details about the California end of the program, but Bill Campbell, who preceded me on this panel, was kind enough to send me a batch of data, including a number of letters on the subject, and I also have a communication from Al Hunter a few years ago about his connection with the Texas section and how he commuted between Oregon and Crystal City, Texas.

Paul Roberts, who headed the latter part of the Emergency Rubber Project, became Project Coordinator with communication lines to Washington where Dr. W.E. Rands, ARA head, administered the top-level technical material. Many PMA specialists from Texas and Oklahoma attended the first organization meeting and some of them doubtless served in one capacity or another. The organization structure was set up at a meeting held at the Texas A & M College on December 29, 1949.

Plantings were made in a variety of soils but mostly the Uvalde silty loam and fine sandy loam soils in Dimitt, Zavala, Eagle Pass and the Ft. Stockton Counties. They tried to avoid noxious weeds such as Johnson grass and bermudas.

Charcoal rot occurred in various acreage, but not always where cotton had been grown as was expected. Of particular concern was the appearance of a purplish condition of the cotyledons which, again, caused loss in one place and not in another. No mention was made in the material I read of the seed varieties used but I presume it was #593.

What also puzzled me was what happened to the seed production of that project. I am aware that in Salinas up until a few years ago there were quite a number of drums of seed which were subsequently sold to Mr. Anderson, but of the Texas-produced seed I have no knowledge. Perhaps someone here at this conference knows the answer.

The project known as the Stanford Research Project was funded by the Office of Naval Research in 1946. Fortunately, in this case, Dr. W.E. Rands explained the motivation behind the operation in his Foreword to the 98-page Stanford Report. "...in spite of the advances of synthetic elastomers, a small but highly important fraction of rubber needs for either civilian or wartime economy could only be met by natural rubber. Because of the vulnerability of existing sources of *Hevea*

rubber to curtailment by shutting off sea lanes; loss by civil disorder, to artificial restriction and to disease, the best interests of a national security demanded the establishment of a small but sound and readily expansible source of natural rubber supply within the continental limits of the United States."

That, it seems to me, sums up the reasons better and more succinctly than I have encountered heretofore. But it was written in 1946. Would it apply today?

The section on Genetics was led by Dr. Reed Rollins who is with us at this Conference. His associates were David G. Catcheside and D.U. Gerstel. Their study of the cross-breeding of large varieties such as P. stramonium with straight P. argentatum pointed to a marked value in developing a superior rubber hybrid shrub.

Here again I feel inadequate for any additional discussion of genetics with Mr. Rollins on the panel as well as Dr. Benedict and Dr. Bonner who worked on the Physiology and Biochemistry sections, respectively, of the Natural Rubber Research Project in 1947-48.

Others who took part in the SRI study included Phillip N. Brooks who assisted Dr. Benedict; Waldo B. Maher who prepared the section on Analysis and Carl A. Taylor, the section on Grafting.

The Extraction and Processing Investigations of this project were funded by the Strategic and Critical Stockpiling Act of 1946. Four sections were outlined for investigation, namely Latex Lab Extraction, Analysis and Testing, Physical Testing and the Pilot Plant Section.

Staff was assembled on June 2, 1948 at the Alisal Station in Salinas with a complement of 29 employees. Project leaders were Dr. Ralph W. Planck, Kenneth W. Taylor, Frederick Clark and Dr. E.P. Jones. Dr. Irving C. Feustel was head of the BAIC unit. The initial appropriation was $179,000.

The Stockpiling Act had directed the Secretary of Agriculture to conduct all phases of research on the domestic production of natural rubber. The objectives emphasized the need for new and improved methods of extraction and processing of high quality natural rubber--obviously guayule--plus the development of possible by-products from the rubber plants and the translation of these methods into economical factory-scale operations.

In July of the following year, funds were cut 40% by Congress. This included the Latex Section and By-product utilization. Rationale for the cut stated that these were of least importance as emergency subjects and not vital to factory-scale applications. The staff was reduced to 17 employees.

This naturally produced frustration among members of the project. Just who made the decision might be of interest if we knew. I can say that he lacked vision and understanding. Today the by-products' potential is considerable. It has been estimated that by-products from the guayule resin could equal the value of the rubber, pound for pound.

Economy in government expenditures, like motherhood, is of course an untouchable, and anyone who argues against it will be labeled ipso facto a heretic or worse... unless there exists a little nepotism or some old military tie with the industrial complex.

There is a great deal of information in the Final Report of these investigations. Several technical papers were subsequently published by members of the

staff. But I don't think the real importance of this post-war research found the same audience as did the wartime activities. Yet, it might be said that the conditions under which this research operated, being less hectic than those during the war, made it possible for its personnel to achieve advances and improvements of great value.

Improvements with batch mill controlled milling, storage studies and mill equipment studies advanced the art. A new plant had to be built, since the old one used by the ERP was inadequate.

Toward the end of the wartime period, some work had been done with the paper Jordan mill in conjunction with Dr. Robert Emerson at CalTech. Dr. Emerson had given much of his time and efforts to the Little Guayule Project at Manzanar, designed to help the interned Japanese produce something useful and equal to their talents and skills.

Strangely enough, the Jordan mill had been considered as a possible milling unit back at the beginning of the century when the coterie of Wall Street tycoons organized the big rubber complex in Mexico. But for unknown reasons, the chemist, William Lawrence, selected the tube/pebble mill common to mine milling equipment in place of the Jordan.

The Jordan mill proved to be an important new development in the line milling process, although I do not believe that it was utilized to its full extent in production flow operations. Ken Taylor will doubtless tell you more about the Jordan and its superiority over the pebble mill.

Toward the end of the NREPI sample quantities of high quality guayule were shipped to various rubber manufacturers for testing and use. Although all of them did not reply in detail, there is no doubt that this new deresinated guayule proved very successful in most cases. One of them was the field test of the Firestone truck tire which I described in my article which appeared in the March 1975 issue of Rubber World Magazine.

So where does that bring us today? The great improvements developed at Salinas in the late 1940s and early 1950s faded behind the more spectacular developments of the cis-polyisoprene chemical rubbers. The rubber manufacturers liked the high-grade synthetics because of the close quality control and consistent supply. After all, some of the tire companies owned synthetic rubber plants too.

Perhaps the worst factor against guayule was that no one was growing the shrub any more. And what we now call the energy crisis was only something the doomsday prognosticators hinted at in books and articles that found few serious readers.

The post World War II guayule research didn't clear up every unsolved problem relating to the guayule shrub or the rubber, but it came pretty close to perfection at a time when no one paid any attention.

But today? The hard facts and predictions are in. Conservation and economical utilization of our energy resources are in the programs for survival. From many years of study of guayule, I believe that it is one of the raw materials and substitutes for synthetics that we need in this country--without the shadow of a doubt. Let us hope that this conference brings us a little closer to that realization.

GUAYULE SEED TREATMENT AND NURSERY PRACTICES--1942

John Emerson
Formerly in Charge of Nursery Operations, Emergency Rubber Project

Introduction

The Government purchased 22,800 pounds of guayule seed, several hundred acres of land, including a 20-acre nursery, a number of buildings, nursery and seed treatment equipment, a mill and other property from the Intercontinental Rubber Company.

The Government also had access to about 30 years of experience of the Intercontinental Rubber Company, chiefly through Dr. McCallum who agreed to act as a consultant.

It was decided from the beginning that we would follow the recommended practices of the Company until better methods were proven.

Immediately it became evident that the following essentials for a successful nursery program had to be met:

First - 500 additional acres of nursery seedbeds had to be available for planting by April 1. This required leasing about 750 acres of suitable nursery land close to Salinas.

Second - Overhead irrigation had to be acquired and installed for the 500 acres of seedbeds.

Third - Additional specialized nursery equipment such as seed treating machines and seeders had to be built and delivered by March 20. Also a considerable number of tractors and ordinary farming equipment for seedbed preparation had to be purchased and delivered by March 20.

Fourth - A seed treating plant had to be designed, contracted for and completed by March 20. This required a building 80 x 108 feet equipped with temperature and humidity controls, 13 additional seed treating washing machines, several hundred shallow trays and other miscellaneous equipment.

Fifth - An experienced seed man and several experienced nurserymen had to be on the job by early March. These men were transferred or detailed from the Shelterbelt Project and several Forest Service Regions.

Sixth - 945 miles of redwood duckboards (3-1/3 million board feet) had to be purchased, cleats installed and delivered to the nurseries by March 20.

Seventh - Construct, equip and staff a 300-man labor camp to provide common labor for the nurseries and field planting.

Eighth - The target date to begin seeding was not later than April 1. It had to be met.

The project was soon well organized to accomplish these and other equally important objectives. The following service divisions were set up and staffed:

a. Procurement and Supplies
b. Land Acquisition

c. Engineering
d. Operation - Fund and Budget Controls
e. Personnel Management
f. Planting and Nurseries
g. Fiscal Control for Bookkeeping and Disbursements

Nurseries

Approximately 750 acres of land in the vicinity of Salinas were leased for nursery production in the spring of 1942. Three nurseries were established providing for 500 acres of seedbeds.

Overhead Irrigation System

The first big nursery job was the installation of overhead irrigation systems for the seedbeds. The Engineering Division, under Jim Byrne's direction, laid out and constructed these systems. The job consisted of drilling several wells up to 500 feet deep, laying 15 miles of water mains and laterals and installing some 85 miles of sprinkling pipes and an equal mileage of four-foot high snow fence for windbreaks. Approximately 100 gang oscillators were required to rotate the overhead pipes which were supported on 4" x 6" redwood posts eight feet long and set two feet in the ground. 33,000 posts were used. The snow fencing was also attached to the posts that supported the sprinkling lines.

Seed Preparation: Carl Taylor, an experienced nurseryman and a specialist on seed collection, storage and preparation, was transferred from the Shelterbelt Project to operate the seedhouse. The Company recommendations were followed without deviation in preparing the seed for spring sowing at the Salinas nurseries. A number of improved procedures were adopted in seed preparation for sowing in the enlarged nursery program which began in the fall of 1942. About a week before the actual operation was to start, seed treatment began. The method developed by the Company was to put 30 pounds of seed in a specially constructed machine which washed the seed in a continuing flow of water for eight to ten hours. The water was then drawn off and replaced with a solution of calcium hypochlorite. The hypochlorite treatment lasted two hours, after which the seed was rinsed with water for a few minutes. The seed was then placed in a laundry centrifuge and the excess water removed. A battery of 14 washing machines and two centrifuges were used in the spring of 1942.

The treated seed was then put into shallow trays which were placed in racks in the seedhouse where both temperature and humidity were controlled. After three to five days the seed had pre-sprouted and was ready for sowing.

Treating of the much greater quantities of seed harvested in 1942 and used to plant the additional eight nurseries established in the fall and winter of 1942-43 required revision of the washing system so that batches of up to 1000 pounds of seed were washed and treated. Two batches (2000 pounds) could be treated in a 24-hour day.

The entire seed handling and treating processes were greatly changed as additional knowledge and experience were gained.

Seedbed Preparation: Guayule seed is so small that an especially fine seedbed was required. First the soil was plowed, disced and levelled with mechanical levellers. Next the soil between the pipelines was rototilled to a depth of about

10 inches. This was followed by more leveling and rolling to settle the soil and provide a firm seedbed. The overhead pipelines were 50 feet apart and 400 feet long, providing for 10 beds four feet wide with 11-inch wide paths. The beds were laid out and eight-inch wide cleated boards, called duckboards, laid down each path. The duckboards were used to support the seeders, carts for weeding, cultivators and other equipment which straddled the seedbeds. The duckboards also provided a mud-free path to walk on. (Incidentally, duckboards were only used at Salinas where the nursery soil was comparatively sticky).

From experience gained in growing tree seedlings, many of us thought a sandy loam soil handled best for nursery production, but Dr. McCallum's recommendations made us cautious. Luckily, however, one nursery at Salinas had a somewhat lighter soil and our experience there early in 1942 led to selection of sandy loam soils when we greatly expanded the nursery program in the fall of 1942.

Sowing: Sowing the seed immediately followed soil preparation. A tractor-drawn seeder, developed by the Company, was used. This machine straddled the seedbed; its wheels travelled on the duckboards. It was composed of two hoppers and two rubber belts. The forward hopper was loaded with a mixture of moist pre-sprouted seed mixed with dry sawdust to make the seed flow readily. The seed was fed on to the traveling belt which dropped the seed into shallow troughs pressed into the soil. Sand from the second hopper was fed onto the second belt which evenly spread it over the seed bands to a depth of about one-eighth inch. One machine sowed about three acres of seedbeds in an eight-hour day. Each nursery was provided with three machines. Seeding began about April 1 and was completed about May 15. There were, of course, inevitable delays because of rainy weather and breakdowns of equipment. There were also problems in gearing the seed sprouting operation so as to have just enough pre-sprouted seed ready without too much each day.

Irrigation: Irrigation began immediately following seeding. The beds were irrigated for only a few minutes each time, three to five times a day until the seedlings emerged and became established. Usually this was about ten days. Then the frequency of irrigation was tapered off and only enough water provided to keep the seedlings thrifty. The amount of irrigation required good judgment on the part of the nurserymen.

Disease and Insect Control: My memory is practically blank regarding disease and insect problems. I remember that we had some damping off, but I don't believe the losses were very great.

Weed Control: Guayule seedlings are small and they did not grow as fast as the weeds. In the beginning the weeds were individually pulled by hand. This job turned out to be much greater than we had anticipated. At one time we had more than 3000 men, women and children pulling weeds. We used trucks and buses to haul these people as far as 30 miles. We got the job done, though. One day one of our nurserymen talked to a Salinas Valley vegetable grower who told him that some of the growers were experimenting with weed killers in the way of sprays. He suggested we try stove oil. The nurseryman was given permission to experiment and had pretty good success. Then he became overconfident and sprayed several hundred feet of seedbed and most of the guayule died. However, from this early experimenting with oil sprays we found that many factors influenced success. Some of these were night temperature, moisture on the guayule seedlings from irrigating, time of day, etc. Several of the nurserymen and others worked with the problems and before the summer was over we could kill most of the weeds with an oil spray so that the expanded nursery program was not faced with any great weed problems. In later years it was found that by preparing the seedbeds about two weeks before sowing permitted the first

crop of weeds to come up and be easily killed with sprays. The second crop of weeds that came up with the guayule seedlings were less vigorous and could be easily controlled with hand weeding and spraying.

When the seedlings reached a height of three to four inches, especially constructed cultivators were used to loosen the soil and remove late weeds between the bands of seedlings. Each nursery had at least two of the cultivators.

Inventories: Several inventories were taken to keep an up-to-date estimate of the number of plants that would be available for field planting so that sufficient land was leased and so Hank Lobenstein could prepare for his transplanting job which was to follow the spring of 1943.

Lifting and Grading: A few days prior to field planting, the seedlings were lifted, graded for size and packed in crates for shipment to the planting fields. About two-thirds of the tops of the seedlings were removed first by use of a special mover equipped with a conveyor and hopper for removal of the tops from the seedling beds. The mowing operation removed most of the leaves which was essential to obtaining good survival after transplanting.

The topping operation was followed by undercutting with a bed digger similar to those commonly used in conifer nurseries. This machine straddled the bed and had a four-foot long horizontal knife which travelled at a controlled depth in the soil and had lifting fingers on the trailing edge to heave the plants and loosen them for hand pulling. Undercutting was done to a depth of about six inches.

The seedlings were hand pulled and taken to a grading shed where they were placed on a travelling belt. Mechanically damaged plants and those less than 5/32" in diameter at the root collar were discarded. The 5/32" diameter size was selected because of the poor results secured from transplanting smaller plants grown by the Company in the spring of 1942.

The plants selected were packed in standard lettuce crates which were lined with waxed paper. The plants were packed in layers with the tops to the outside. Between layers moist shingletow or spagnum moss was placed over the roots.

Some of the areas planted were located a considerable distance from the nurseries and stock was sometimes in transit and storage for several days due to the difficulties in exactly coordinating the nursery operations with the field planting. Variations in weather conditions at widely separated points sometimes disrupted scheduled operation. When possible, shipment was made in refrigerated vans and the crated seedlings were stored in refrigerated rooms with temperatures of 34-36° F. Under these shipping and storing conditions the seedlings usually reached the planting machines in good condition. However, when refrigerated trucks were not available, transportation was at night and if necessary, stored in well-ventilated sheds.

The dormancy of the seedlings and the amount of moisture of the plants when packed had considerable influence on the length of storage they could stand without damage from disease before planting.

Since the Company lacked much experience in shipping, packing and storage of seedlings, we learned the hard way--by trial and error.

While I had no part in it myself, I understand that very good seed and nursery manuals were prepared and published near the end of the project. These manuals should be available in case a new program is started.

As we gained experience and results of research became available the seed handling and nursery practices underwent considerable change. I have mentioned some of these, but briefly some of the important changes included:

1. The seed was threshed to remove the floral parts which adhered to the seed when it was collected. This resulted in a small, hard shelled seed and reduced the bulk by at least two-thirds. The threshed seed requires less treatment and pre-germination, and can be planted dry enough that it will flow through a drill that eliminates the need for covering the seed with sand. An ordinary drill used for planting coniferous seed in nurseries can be easily adapted for this use, thus eliminating the cumbersome and expensive machines with belts that were used on the project.

2. Lighter soils than those at Salinas were found to be more suitable. A loamy sand appeared to prove out best. This provided a better seedbed, eliminated the use of duckboards and got the workmen out of the mud.

3. Weed control was greatly simplified by preparing the seedbed far enough in advance of sowing so that the first and big crop of weeds were destroyed before the seed was planted. Oil sprays were developed which killed most of the late germinating weeds. This greatly reduced costs.

4. Grading the seedlings for field planting was simplified by controlling the density of the seedlings in the seedbeds so as to produce a maximum number of usable seedlings per square foot of seedbed without an excessive number of culls.

5. Improved packing, shipping and storage methods were developed.

Many other improved practices were developed and used before the program ended.

Expanded Nursery Program

Before closing I should briefly mention the enlarged nursery program that began in the fall of 1942. Sometime during the summer of 1942 it became evident that we could expect a big crop of seed from the nursery beds and from the field plantings near Salinas. It was decided to try to greatly increase the seedling production for the 1943 planting season by establishing a number of new nurseries in California, near Bakersville, San Clemente, Oceanside and two near Indio; also at Phoenix and two in Texas at El Paso and Edenburg.

Suitable sites were located and all of these nurseries were established and planted on schedule. All of the nurseries in California were a success, but we encountered many difficulties at the Phoenix and Texas nurseries. All of the California nurseries were large. The largest contained at least 400 acres on the Bell Ranch between Palm Springs and Indio. Those in Arizona and Texas were about 100 acres each. Incidentally we built a 600-man labor camp at the Bell Ranch Nursery, principally to house labor for the installation of the irrigation system and to pull weeds. Fortunately this camp was used very little due to the improved weed control practices.

I have purposely avoided going into detail regarding the seed treatment and nursery cultural practices. First, my memory, after 33 years, is not as good as I would like it to be and second, there are excellent seed and nursery manuals available that will provide the details to anyone interested.

While seed collection responsibilities were shared with the Division of Planting and Harvesting, I did not personally participate in that activity so Hank Lobenstein will cover that subject.

I will be glad to try to answer any questions you may have.

Question: Is there any particular reason why there were problems in Texas and Arizona which you just mentioned and not in California?

Answer: (J. Emerson) First, I think it was the remoteness from our headquarters at that time in Los Angeles. There was a problem in securing the irrigation pipes and the system of getting it in. Secondly, at that time equipment was in very short supply and we had a great deal of trouble in getting tractors and other equipment. Weather conditions also caused problems; we were trying to grow guayule in the middle of winter. For instance, in Phoenix, which is supposed to be relatively frost-free, in January it freezes ice occasionally. We had some real cold weather there and we had some problems with that; I can't tell you all of them. I know that those programs were not as successful as those in California.

Comment: (Robert Hilgeman) I might elucidate a little more on the Phoenix situation because I was in charge of it. You are correct. We planted seed all year around and we had little success in January, November and December; it was too cold. In the nursery we had a problem, which Dr. Presley probably remembers, with sandsplash in the summertime. This was apparently a mechanical injury on the small leaves because of the sprinklers. As far as I know there was no fungus involved. We reduced the problem by irrigating only in the late afternoon or evening.

The one thing I wanted to mention was that beginning right away in 1943, we tried planting in the manner lettuce was planted--on beds with preformed units and two little planters. We had no success starting in May. In June, July, August and September we had fairly good germination. By this time we were learning about planting and the September and October plantings were successful. But we had an invasion of mealworms and some rain and we had no plants left after about the middle of November. In March we made quite a large planting, using the Planet Junior Planter, which the lettuce growers were using with a wider shoe. I think they called it a carrot shoe and no packer wheel. We produced a wonderful stand, which we kept until the next spring. We felt that we solved the problem of growing in the field. There was a great variation in the size of the seedlings; still it was a successful program.

Question: In your judgment, do you feel there is much point in working on the direct seeding of the guayule plant in the field, eliminating the nursery stage? Would there be much chance of success, in your opinion?

Answer: (J. Emerson) In my opinion, no. I don't think so. I think there are too many factors that affect it. We found that the seedbed must be irrigated to get the seeds up and established. Sure, you're going to have some good luck in field planting if you just happen to hit the weather right with rain at the right time. Guayule seeds have to be covered shallowly. Irrigation brings water right over to it; I think there will be problems in washing it out and burying it.

Comment: (H.M. Benedict) There were plantings out in the old Spence field and we thought they were fairly successful, considering the methods employed and the time we had to work on it. We never knew what the final results were, yet if I might express an opinion, I feel that the study that Dr. Hilgeman has reported indicated that it can be successful and I really feel that the elimination of the labor costs

involved in nursery and transplanting work is something that should really be aimed for. At least I would hate to write off the direct seeding approach.

Comment: (J. Emerson) I don't pretend to be an expert on it at all, it's just my opinion from my experience in the nursery that I would question the practice.

FIELD PRODUCTION AND HARVESTING

Henry L. Lobenstein
In Charge of Field Plantings, Emergency Rubber Project

The comments I wish to make concerning the topic assigned to me are based upon experience on the Emergency Rubber Project during World War II as discussed earlier in this session by Mr. Droze and others. On this guayule production project I was in charge of field production.

I would like to divide my comments into four principal activities which are: (1) site preparation, (2) planting, (3) cultivation and (4) harvesting.

Site Preparation

If the site on which the guayule is to be grown has already been used to grow cultivated crops, this part of the job requires a tillage job such as might be needed for a new crop of corn or maize. However, such tillage would need to work the soil to a considerably greater depth than would be done for other commonly-grown row crops. The reason for this is the need to loosen the soil to a depth at least equal to the length of the roots of the guayule plants as they come from the nursery.

If the planting site is new land, the native vegetation must be uprooted, and the residue from such operation should be dried, raked, and burned or removed from the site by other means. Actually, needed jobs would be the same as if the site were being cleared for the growing of other commonly-grown dry land row crops. After the clearing job is accomplished, the site should be prepared as described for land already in cultivation. However, it must be kept in mind that if the guayule crop is to be irrigated, then the necessary leveling will need to be accomplished before the final preparation is done.

In the event that direct seeding is found practical, then final site preparation will need to be more finely done, somewhat in the nature of the degree of preparation required for the seeding of a crop of sugar beets.

For all of the operations mentioned in this part of my remarks, commonly-used farming equipment will do the job with perhaps a few adjustments or modifications.

Planting

During the operation of the guayule project, field establishment by direct seeding was only in experimental stages. If it should be developed into a desirable practice, then the seeding job could be done with multiple row seeders similar to those used for sugar beets, carrots, and other fine-seeded plants. Again, minor modification of commercially-available machines might be necessary, especially to provide for proper row spacing, rate of seeding, or other similar factors.

Our project planting was done using one-year-old nursery-grown seedlings. These were undercut in the nursery beds to a depth of about seven inches and the tops were cut back to a length of 3-1/2 to 4 inches. These seedlings were thus fairly good-sized plants and were branched and somewhat woody.

The field scale transplanting of stock of this size is, therefore, not a simple job. If a desirable output per man-day was to be attained, it soon became obvious on the guayule project that multiple row semi-mechanical transplanters were the answer. The Intercontinental Rubber Company had developed such a machine which was acquired by the Emergency Rubber Project along with other company assets. This machine was tried but was found to be far too heavy, cumbersome and slow for efficient field operations.

The project therefore developed, constructed and used a mechanical multiple-row transplanting machine which worked out very well. These machines were an adaptation and refinement of tree planting machines developed and used by the U.S. Forest Service for tree planting on the Prairie States Shelterbelt Project.

Project operations used four-row transplanters mounted so that row spacing could be readily changed. In this matter of spacing, it will vary according to the ultimate age to which the guayule plants are to be grown. Basically, each unit of these machines performed the following:

1. Subsoiled the row to be planted to a depth sufficient to accommodate the transplants with their 7-inch taproots.

2. Opened and held open momentarily a slot sufficiently wide and deep to accommodate the seedlings.

3. Inserted the seedlings in the planting slot to the correct planting depth and held them in this position until the slot was closed.

4. Packed the soil firmly around the transplants.

When properly operated, it was found that the machines actually did a better job of planting than could be done by hand and, of course, at a much more rapid rate. It was found that slow, steady traction was needed and that the medium-sized crawler tractors were much more satisfactory than wheeled outfits.

The transplanting machine itself required the following crew: a machine foreman, one man for each row unit, and a man whose job was to keep the planters supplied with transplant stock. Four-row units therefore required a total of six men plus the tractor driver.

Field planting could, of course, be done by hand, but it was a slow, laborious task. If done, the most satisfactory method would be to use a technique similar to that developed and used by the U.S. Forest Service in the transplanting of seedling trees and shrubs. If heavy soils are present at shallow depths, subsoiling the shrub row to a depth of eight or nine inches prior to transplanting will produce a better and faster transplant job.

Cultivation

The field care of guayule plantations is basically no different from that required for other row crops grown in the area. The sole purpose of cultivation is

that of keeping the planted field free of other vegetation so that the planted crop will have sole access to available soil moisture.

No special cultivation equipment should be necessary. That commonly used for the cultivation of maize, corn, or cotton will do the job although some adjustments may be necessary. It is difficult to say how long cultivation should be continued. As a general rule, it can be stopped or at least materially reduced after the plants become large enough to shade most of the ground surface. At any rate, it should be stopped when the plants become so large and woody that they are materially damaged by the cultivation equipment.

Harvesting

Both the woody parts of the top and the main roots of the guayule plant contain rubber in amounts which warrant processing. Therefore, on the Guayule Project, we harvested the entire plant as a unit.

First, the plants were undercut to a depth of about seven to nine inches. This was done with two-row machines having a heavy duty subsoiling shank for each row. To this shank was attached a cutting and lifting blade somewhat like a short (8- to 10-inch) section of a plowshare. With this implement the large, heavy roots were severed to the desired depth and the entire plant was heaved to the surface of the soil. The plants were allowed to dry for several days to permit the leaves to drop and the new terminal growth to dry. The dried plants were then windrowed using a large-size commercial side delivery rake such as that used for mown hay and straw.

The next and final steps were to bale the entire shrub and haul the bales to the storage yard at the processing plant. For the baling operation, a commercially manufactured field baler was used. This machine produced a compact, tightly packed bale about one-third larger than the bale size of similar machines used for hay and straw in most parts of the country. They were fitted with pickup attachments which lifted the dry shrub from the windrow, elevated it, and deposited the loose shrub into the hopper of the baler. Because of the loose, stiff nature of the shrub, it was necessary to fit the pickup attachment with a driven, canvas cover.

Loading of the baled shrub was readily done with commercial bale pickup and elevating equipment.

General Comments

The field operations in guayule growing as briefly described can utilize much equipment available commercially. However, some of the equipment, especially the transplanting machine and the digger, was not available and project construction was necessary.

In the case of private operations, especially with relatively small individual fields, such equipment would be far too costly for an individual. In my opinion, this should be no deterrent to a guayule growing program, for this equipment problem could be met by the pooling of operations, perhaps through a cooperative organization or, possibly, by group contracts with an equipment operator having financial ability to procure and operate the specialized equipment.

Question: In your discussion about cultivation practices and specifically weed control measures, you talked, I think, only about mechanical means. Does that mean that the spray oil herbicides were used only by the nurserymen?

Answer: (Henry Lobenstein) No, not at all. In the latter years of the project, we did use some oils, and there is no reason whatever that with the very much improved herbicides that we have today that they could not be used much more extensively than we did.

Question: (Ed Marzuti) Has any recent research been done like two- or four-row planters now where they have herbicides and insecticides and fertilizer attachments all in one where you can do it all at one time? Has anything like that been done with guayule?

Answer: (Henry Lobenstein) Not to my knowledge, sir, although I would remind you that it has been 30 years ago that the project was closed; but I would add this: I see no reason whatever that it could not be done just with a little ingenuity.

Question: How about fertilizer? Commercial or steer?

Answer: (Henry Lobenstein) We did not use any fertilizer in our field plantations on guayule. I would say that if you want to increase the hydrocarbon content of a plant, you better stay as far away as you can from excessive vegetative growth. In other words, if you want an apple tree to bear apples, do not put too much nitrogen on it. What you have to do when you use fertilizer is find a balance, and you can only do that by experimentation and trial. Find a balance by increasing your tonnage through the addition of fertilizer without greatly decreasing the percentage of hydrocarbon. Keep in mind that most of the western soils on which the guayule would be growing have an ample supply of potash. There might be some places where a slight addition of phosphate would be helpful because phosphate might be needed. Nitrogenous fertilizer such as nitrate or soda is the one that I would say should be tried carefully and on an experimental basis.

Question: One thing that you did not talk about at all was irrigation practices. How much water was required for different climates, etc.?

Answer: (Henry Lobenstein) We grew guayule both under irrigation and under dry-land conditions and I think that probably if we hadn't been under the tremendous war pressure that John mentioned this morning, we would have grown a lot less of it under irrigation than we did. These were two primary reasons that we went to irrigation: one of them was to speed up, get as much rubber as you can in the next couple of years, and the other was to extend its growing area into some areas--like Bakersfield for example--where the normal rainfall was not quite enough for guayule. In many cases, I would say we made the mistake of over-irrigating. However, there are some things in favor of irrigation of guayule that you don't encounter in growing other plants. In my opinion, I would say that for the long pull, for a good stand, reasonably good growth and high rubber percentage, that you are looking for something in the range of 16 to 18 inches of rainfall. If you want to grow guayule in a place where annual rainfall is only 12 or 14 inches, you might have to irrigate two or three times during the summer right after transplanting until plants are established. After that you can supplement that annual rainfall until the middle of winter. As Mr. Presley mentioned, if you irrigate in the middle of winter, you probably escape quite a lot of the disease problems that you get from summer irrigation. If you are going to do that you've got to be sure ahead of time that you have a soil underneath the guayule plants that is able to store and give up water. You put it on in the wintertime and it will store it so the plants can use it next growing season. But it can be done then, during the dormant season, when you are not using it for other crops.

Comment: (Hilgeman) I think I can give you a little information on fertilizing. In our test in 1943-44, we had nitrogen applied to approximately half of the plants in various soils. In no instance did we ever get a response. It appeared that nitrogen was not needed.

Comment: (Bob Pierson) I might add a little on this matter of irrigation which I've run across in some extended literature work on just not merely guayule but the entire field of plants. There is among my souvenirs a U.S. patent, and I forget which plant it is on, but it's one of the plants that will produce hydrocarbon. More particularly, the isoprene type hydrocarbon. Among the conditions that they give for growing are that the hydrocarbon seems to be formed as a result of a drouth resisting mechanism. Therefore, the amount of irrigation that is used should be very scrupulously watched because over-irrigation could be as bad as under-irrigation.

Comment: (Henry Lobenstein) Absolutely, we found that to be our experience. If you're going to grow it in a field that receives 10 to 12 inches average rainfall, for goodness sake, don't put on 26 inches.

Question: (Joel Schechter) We note that when you are harvesting you remove the plant together with the roots. We understand that this gives you additional rubber right at the time of harvest, but is there any experience for harvesting just the upper aerial parts and allowing the roots to regenerate?

Answer: (Henry Lobenstein) There was some harvesting done with younger age plants.

Comments: Could I comment on that? Yes, we harvested some acreage using a method called "pollarding" where we harvested the aerial portion of the plant and left the roots, and this worked very well. We used an ordinary mower to mow the tops off and we used a side delivery rake to put it in the windows. Then we came along with the balers and harvested it in the customary manner.

Comment: (Henry Lobenstein) I think that one of the reasons for digging, as I understand it, is that the bulk of the rubber is in the basal portion of the plant above the ground and the larger roots. Sure, you can cut off the top, but you can't cut them off too far with the immature, woody plant or it's not going to resprout. But you could get a small percentage of your total rubber output by cutting off those tops. What little bit we did indicated this: that if the plants were two or three years old, we could mow the tops with reasonable success; but if they were older than that and we cut those tops off, we got some real losses because they just didn't sprout fast at that age. They were too old to sprout.

Comment: (Eleanor Taylor) During the research project following the emergency rubber project during 1947 to 1953, a study on pollarding was conducted on mature shrubs. It was harvested, as I recall, when it was about five years old. It was harvested by clipping or pollarding and allowed to regrow for four years. The yield for those two harvests exceeded the yield on the plants that had been allowed to continue through. I don't recall any data on survival. It was not any great loss as I recall from the clipping itself and the yield was increased markedly.

Comment: (Henry Lobenstein) My own viewpoint is to find some way of pollarding only part of the plant so that some internal growth were left--enough to start new growth.

Comment: (Ken Taylor) Mr. Lobenstein mentioned that during harvesting operations as they were conducted during the Emergency Rubber Project, the plant was dug and allowed to lie in the field and dry until most of the leaves fell off. In our subsequent investigations following World War II, we found that this was an undesirable

practice because the quality of rubber as measured by the potential molecular weight of the individual isoprene molecule tended to decline with age of exposure of plants to the conditions that existed in the field. If conditions in the field were not controllable and did not contribute materially to any beneficial aspects of rubber recovery, we found that there were other means of coagulating the latex within the plant. We found that it was highly desirable to move the plants from the field to the processing mill rapidly and allow as little deterioration as was possible in the field.

Question: (Henry Lobenstein) In those later studies, did you have to keep the shrubs in a loose condition, or could they be baled immediately after digging?

Answer: (Ken Taylor) No, we routinely baled it. From the standpoint of ease of harvesting, that would be the way to do it, or use a machine like the currently used pickup garbage collectors that compact the material in a truck.

Comment: (Henry Lobenstein) I would say this as far as moisture content of the plant is concerned. There is no reason whatever that you could not run the baler over the field immediately after you have dug the shrubs.

Comment: (Tysdal) Speaking on the pollarding that Miss Taylor brought up, I think that it is quite an important field. We did some additional work on different ages and I think the recovery is better on the younger plants. Yet we got good survival on some older plants. Another thing I wanted to mention: when we cut the four-year plants and then let them grow again, we got much higher yields in another two years than if we transplanted seedlings.

Comment: (Leslie Baird) As an outside observer I'm more interested in any harvesting aspect than I am in a matter of pollarding. It seems to me that while it hurts the nursery people a little bit, under conditions of the ERP you had the problem of getting the rubber as fast as you could because of the war emergency. Where fields are going to be in guayule for a long period, it would be important and maybe that is in the study that Eleanor was speaking about. The point is you always have your root area which, of course, does contain a certain amount of hydrocarbon and maybe the second or third time over a period of years you take the entire plant and you haven't lost anything. I feel that it probably is one of the most fortunate aspects of that type of harvesting.

Comment: (Member of the audience, unidentified) About 25 to 30 percent of the rubber is in the root.

Comment: (Henry Lobenstein) On the guayule project we used to roughly consider a third of the rubber content of the mature plant was in the root section. One other point I want to make: As far as direct seeding in the field is concerned, I don't know whether it is practical or not, but a lot of you people are very familiar with desert and semi-desert conditions. You heard Mr. Emerson describe this as a small seeded plant but under a desert climate, you are not going to get a very high percentage of germination from the seed you put in the ground. If direct seeding comes into the picture, I'm convinced it's got to be done something like what was mentioned this morning, along the line of lettuce or something like that. Also, in the climate that you're going to be growing it in you've got to figure on having a lot more seed than you expect to have plants.

Comment: (Reed Rollins) I want to comment that guayule has the characteristic that is not present in many other plants. There are a very large number of buds way down

on the stem including the roots, so that even the roots will sprout. They produce what are called retonos. This is a fortunate feature of the plant and as I say, not common in many other plants, many woody plants in particular. In that respect, it seems to me that it is very well adapted to pollarding.

Comment: (John Emerson) We've been throwing this seed collection report back and forth between us and I did intend to talk about it a little bit, but as long as you're up there, tell them a little about seed collection.

Comment: (Henry Lobenstein) Very simple. You just take your little two-row machine and put a power operated spiral brush over it that will run over every row with a sliding hopper underneath. It is the simplest job in the whole operation.

PROPAGATION FROM CUTTINGS

K. Emerson

The Manzanan Guayule operation used cuttings for a great deal of their propagation, and their techniques have been described in detail in Nishimuna et al., American Journal of Botany 31:412 (1944). Cutting material was obtained from the Salinas Project. The clipping of the nursery stock prior to transplanting provided large quantities of suitable material. The stand of guayule obtained was reported to be "more uniform than a comparable stand of plants grown from seed, and... produce seed earlier and more abundantly than seed-grown plants." One experienced man was able to set as many as 7000 cuttings per day in the bed. Irrigation was necessary immediately upon transplanting, as is the case with seedlings.

These results were obtained under climatic conditions a long way from optimal; the Owens Valley has hot summers and cold winters, with temperatures of 0° F being reached occasionally in winter.

Cutting propagation may be especially useful if high yield strains can be developed by plant breeding.

EXPERIMENTAL PLANTINGS IN ISRAEL

Joel Schechter
Research and Development Authority, Ben-Gurian University of the Negev

We're quite new in the guayule game and have only recently begun with our studies on guayule. Actually, we did plant out a few plants in our botanical garden several years ago in the framework of a general introduction program in which we brought species of plants from the deserts throughout the world. Unfortunately the municipality built roads through our botanical garden and wiped out completely the plants that we had growing there. So we were not even able to get results from that study. A few years ago, in light of the development of rubber prices, we decided to have a look again at the possibility of growing guayule in the Negev. We did run into some difficulty obtaining seed of the improved varieties which we had heard had reached over 20 percent of the rubber content. We obtained seed from the Fort Collins seed storage laboratory and using this seed we began our program.

The area that we are talking about is an area just north of Beersheba in which the natural rainfall is from 8 to 14 inches and is exclusively winter rainfall. We have a hot and completely dry summer. The soil is a sandy to sandy loam and is mostly quite deep so that we do have the water storing capacity spoken about previously. We have fairly mild winters, very rare frosts and not very hard ones. The crops in the area generally respond well to irrigation; however, the big problem that we have is water supply as 95 percent of the potential resources of Israel are already exploited. When we examine the feasibility of growing guayule in the Negev we have to compare it with any possible alternate use of the same amount of water. Land is less restricted. There are some restrictions on it but still the major factor will be the alternate uses of water.

As I mentioned, we did get the seeds finally from the National Seed Storage Lab in Fort Collins; we got something like 25 different lines. These were sown in flats, using an artificial soil mixture of one-third soil, one-third compost and one-third sand. All of the soils were previously treated with methylbromide so we did eliminate the problem of weeds. A certain amount was also sown in polyethylene bags; in this case about three grams of seeds per hundred bags were used and each bag had something from five to ten seeds. The germination tests showed that all lines, even after the seeds must have been something between 20 and 30 years old or more, had at least 50 percent germination with some reaching 70 or 75 percent. The seed which was planted in bags had approximately 90 percent germination in the bag. Ninety percent of the bags had at least one plant in them. The seeds were treated very simply by soaking for 18 hours or so in tap water; some hydrochloride solution was added and just last summer they were transplanted to the field in a plot of about one acre. We are quite short on seed, so for at least the near future we will have to maintain very small experimental plots until we can produce our own seed, which has already begun, incidentally.

It is said that the best way to kill a program or a new project would be to give it to an economist to make a feasibility study. We did that, realizing the dangers involved in a feasibility study. Nonetheless we think it very important to at least determine those parameters which are critical for the development of the program. The study did indicate several important things. First of all, today Israel imports about 20,000 tons of rubber per year of all types--both synthetic and natural. It is predicted by 1985 it will be someplace in the vicinity of 50 to 60,000 tons of rubber imported per year. About 80 percent of this is general purpose rubber and hence we could see that in ten years' time there could be a market for about 20 to 30,000 tons per year of guayule rubber. In addition, imports today for pulp and paper manufacture run something in the area of 55,000 tons per year. It was seen that there would also be a sufficient market for pulp if the pulp were the proper quality for paper manufacture. As far as price was concerned, we used the projections of Commodity and Export Division of the International Bank for Reconstruction and Development (World Bank) which predicts that by the 1980s the price of rubber in New York will be about $750 per ton. For some strange reason, the rubber in Israel has been about $100 cheaper per ton and I think it's the only thing we've ever had that's been cheaper than other places in the world. So we took into account the price of about $650 per ton of rubber. Similarly we used the price of about $200 a ton for the price of the pulp. We had no data on resin, either from a technological or an economic point of view. Hence the study was done for 30,000 tons of guayule rubber and another 60,000 tons of pulp. We took a ratio of about two tons of pulp to one ton of rubber, which seems to be in the ball park at any rate. For a developing country one of our great problems is how to save foreign currency and we found that if we could use the pulp as well as the rubber it would save something like 30 million dollars a year in foreign currency. If the pulp

could only be used for fuel, the savings in foreign currency would be only about 20 million dollars a year. This is an important sum; it may be small to Americans when they think of their national debt but it is quite a large figure for us who are contributing to your national debt.

We then analyzed the cost and productivity. For productivity we took several features, that is to say we would harvest after two years at a certain rate per acre, three years and four years at a certain rate of production, using quite a variation of production capacities. We found that our costs, including capital, would come out about $500 per acre if we harvested in the second year; about $800 per acre harvesting in the third, and about $1,000 per acre harvesting in the fourth year. That is not very dependent upon yield. There would be a variation with yield, but we ignored it at this point. In considering our extraction costs, we did run into trouble because we had very little knowledge of the technology of rubber extraction or of the pulp industry. We did use, however, the figures based on the cellulose industry and found that for the size that I mentioned, for 30,000 tons per year production of rubber and 60,000 tons per year production of pulp, we would need a 37-million dollar investment in extraction plants for the rubber plus the pulp and only 17 million dollars a year for the rubber alone. The pulping plant seems to be expensive and we may be wrong here because we are not well acquainted with these figures. Finally we get a cost of $290 a ton for extraction costs for the rubber, about 25 percent of which are capital costs, and about $95 a ton for pulp of which about 50 percent are capital costs. Using these figures we come up to a final income that we would get if we consider a ton of rubber alone without the pulp. We would have to produce it for $690 a ton. We would get a return of $690 a ton of rubber and if we could sell the pulp as well, we would get a return of $1,000 - $1,050 per ton of rubber and pulp together. From this we calculated our break-even yield.

Now we are speaking of an area in which we would have about 10 to 15 inches of rainfall and therefore we would have to add to it about another six inches for the 10-inch area at least. Considering this amount of water, which is fairly expensive in our country, we would have to have a yield of 800 pounds, a sustained annual yield of 800 pounds per year per acre. If we do not use the pulp for paper manufacture, and if we cannot sell it, we would have to have about 1150 pounds per year per acre on a sustained yield basis in order to break even. These are quite high yields if we consider the numbers that were given this morning. In addition, we made a sensitivity analysis of these figures, and if we are off by 25 percent, production costs will be 25 percent more than predicted here. We would then have to reach something like 1,100 pounds per acre per year of sustained yield, and if the price decreased by 25 percent we would have to produce 1,400 pounds per acre per year. If both of these factors came cut in this direction, then we're really in a bad way. We would have to produce something like 2,300 pounds per acre per year on a sustained yield basis. It doesn't look that good at the moment, but we made a second analysis; that is, how does this compare with alternate crops that we can grow with the same amount of water? Here we do not come out so badly if we compare our figures with the figures of wheat. We do grow wheat at the moment and if we start using water for irrigating guayule, we would have to do this instead of growing wheat. Here again, we come out to about the same 800 pounds per acre per year figure, as breaking even with the yield per unit of water, as compared to wheat. This kind of comparison gives a pretty good idea, although I'm not so certain as far as national policy is concerned that the government would be interested in growing rubber instead of wheat. We can live without rubber for a short period of time, but without wheat it is a little more difficult. On the other hand, if we could get a bit higher yield, I think it could be worthwhile to go into the guayule rubber business.

We also compared guayule with jojoba, that other crop we heard so much about today. Here the picture is definitely to the detriment of the guayule. Jojoba does come out far better for use per unit of land or per unit of water than the guayule seems to come out according to these figures.

Again I say that one must be very careful in looking at these numbers. There have been many surprises and I think it would be surprising if there were none in these figures. We are going to go ahead with the program on a limited basis. We have our first area planted out already and we should be getting results in at least another two years when we can harvest the first amount. Thank you.

Question: Is that World Bank economic data available now?

Answer: (Joel Schechter) Certainly, you can ask them for it. I suspect they'll give it to you; I see no reason why they shouldn't.

Question: (K. Taylor) I'm interested in your comments on the germination rates that you got out of the seeds that you obtained from the National Seed Storage Laboratory at Fort Collins. Do you know whether or not that seed at Fort Collins had been held under conditions of cold storage or was it at ambient temperature?

Answer: (Joel Schechter) I would assume that it was cold storage because we kept it for a few months at ambient temperature and found that the percent of germination began to decrease. I couldn't possibly consider that they could have that high germination rate if they were not under cold storage conditions.

Comment: (Quentin Jones) All of the seed stored at Fort Collins was under controlled humidity and temperature, about 40° F. and 40 percent relative humidity.

Question: (J. Johnson) In your feasibility study did you use figures in terms of substitution for land use? In other words, if you were going to use land now being used for wheat or some other purpose did you take into account land being used for this?

Answer: (Joel Schechter) We took into account. We compared the growing of wheat as an alternative for the growing of guayule, and more important than land was the return per unit of water.

Question: (J. Johnson) So some of your figures might change slightly if you were to be making the same analysis in the United States?

Answer: (Joel Schechter) Certainly. Those results apply particularly for Israeli conditions and one should be very careful in applying them here.

Question: Could we find out at this point what the supply of seed is, or what amounts are available at this time?

Answer: (Joel Schechter) All I can tell you about that is that we promised to replace the seed we received from Fort Collins.

Comment: (H. Anderson) When we learned that the government was destroying all the seed that was left over from Salinas, we thought somebody ought to do something about it. So with a little Congressional help we did acquire quite a bit of seed. We don't keep our seed under refrigeration but we do keep it dry, and it has a very fair germination rate; it ranges from 40 to 80 percent. We test our seed once a year. Each year it decreases just a little bit in viability.

Question: (J. Bonner) Did you have information on which you could base a judgment for increment of yield for increment water?

Answer: (Joel Schechter) I wish I had some of that information; it would be vital. What we are saying is very simply that we know from literature, from what others have done, that there should be at least 16 inches of water. If we're working in a 10-inch rainfall area, then obviously we are going to have to add six inches of water. However, your question is very well in place. This will be one of the vital things we'll have to gain from our experimental program before we can reach any optimum of water use. So far as I'm aware there isn't any such information and it would be extremely helpful to know, for example, if you added eight inches instead of six inches, how much increment of value you would get from the additional two inches. This would be one of the parameters which is vital in our program because water use is the critical factor here. All our calculations finally will revert back to use or return per unit of water. This will have to do better than alternate crops. If it doesn't, then for our conditions it will not be worth growing.

The seasonal application of water will also be very important. We would be interested in giving it only in the wintertime. We have more water available in the wintertime than in the summertime. It means that the plant would have to go through the entire summer--something like a seven- or eight-month period--with no water application whatsoever. I was glad to hear Mr. Lobenstein mention this morning that such a thing is not only possible but might be desirable from many points of view.

Question: (Bennigan) Dr. Schechter, I was wondering if your economic projections had given any credit to the value of the resin?

Answer: (Joel Schechter) We give no credit whatsoever to the value of the resin.

Question: The point was made this morning that resin could carry a high value, and along that same line I'm wondering if your studies, or projected studies, included any work on the extraction or processing end of this and if you are going on the basis of work already done, will it probably be adaptable when you need it?

Answer: (Joel Schechter) We are definitely considering going into the chemistry of it, the extraction of it and the use of the resins and in the pulping process. In fact, one of the reasons why Professor Wieniak is here today is that he has been the Head of the Chemical Engineering Department at the Ben Gurion University and we're hoping that they will contribute to this particular research.

Question: (Tysdal) You mentioned a rather high figure, as I viewed it, for the cost after the third and fourth year--as much as $300-400 in one year--or $300. We think of those years as our least expensive. I was wondering if you would explain that or tell us how you arrived at it.

Answer: (Joel Schechter) I don't have the breakdown of those figures here but they are high, I will admit. The economists throw in things you never thought of, including the time the labor force is unemployed and you have to pay them anyhow, or something to this effect. I would rather not give you the complete breakdown. I do consider the figures to be high, to be quite high.

Question: (Robert Dennis) What average yield of wheat did you have, or did you use in the comparison?

Answer: (Joel Schechter) We get two metric tons on an acre, something like 4,400 pounds. It might be of interest that in Arizona the average yield is about like that. In the past year it was about 4,600 pounds, so it's about the same order of magnitude.

Question: (D. Miller) Wheat is always important for pulp in raw material. Did that enter into your calculations?

Answer: (Joel Schechter) We use our wheat for cattle feed and that is already taken into consideration in the return per acre of wheat. In fact, we mix it with chicken manure or we feed it to cattle directly.

REPORT ON ACTIVITIES OF THE CONTINENTAL MEXICAN RUBBER COMPANY

Elbert M. Long

I went to Mexico in May of 1943 to work for the office of Rubber Plant Investigations of the U.S.D.A. and from 1944 to 1949, in the cultivation program of Continental Mexican Rubber Co. I should like to make a few comments about that experience--in writing--because my failing voice is untrustworthy.

The only innovation of ours worth mentioning in guayule cultivation was the use of wheat straw instead of sand to cover the seed planted in the nursery. We found that the straw mulch gave us better germination with less irrigation than sand and was cheaper.

Our field plantings were in newly cleared land in the "Laguna area" north of Torreon. The annual rainfall there was around 12 inches, much of it during the summer. The irrigation water contained around 2000 p.p.m. of soluble solids, but had a fairly favorable Ca/Na ratio. The water was too scarce and probably too salty to consider direct seeding. The stands achieved by transplanting nursery grown seedlings varied greatly and on the average weren't good.

After a year in the field the plants had 7-8% rubber. The Company's experience in the Salinas area led us to expect a steady increase in rubber percentage but the annual increment after the first year was disappointingly small. However, the greatest disappointment was in the increasingly serious loss from root and crown rots after the first year or two in the field. We learned early not to irrigate transplants after they had become established during the summer and not to transplant after the onset of warm weather. But the older the shrub became the greater the loss in stand after each significant summer rain. I left C.M.R. Co. before most of the Cartagena shrub had been milled, but was convinced that the loss from diseases became great enough in approximately three-year old fields to prevent any gain in rubber per acre, and that there was a progressive net loss in rubber thereafter.

Under no circumstances would I recommend an attempt to cultivate guayule in any area with much rain during hot weather. In fact, I think that the price of rubber in comparison to food crops would have to go much higher than at present in order to make the cultivation of current strains of guayule economically feasible anywhere. I do think that a limited research program to develop and test improved strains might be advisable.

DISEASES OF GUAYULE

John T. Presley
Pathologist, Emergency Rubber Project

I would first like to comment on one statement that John Emerson made concerning seedling losses in the nursery; he felt that seedling losses were negligible. I think if John would realign his thinking on the seedling losses, he would find out that actually the losses in the nursery were considerable in relation to the number of seeds planted. As you will recall in Lloyd's monograph dealing with the guayule rubber plant in the Chihuahuan Desert, there is mention of only one disease. The disease mentioned was rust Puccinia parthenii which occurs primarily in Mexico. It has occurred to a small extent on native shrub in South Texas. This leaf rust causes light brown pustules on the leaves and rarely causes much loss of leaves.

We went into the guayule program thinking that we had a plant that was unusually free of diseases. However, when the seedlings started emerging in the nursery, we found that we had post-emergence damping off and on careful examination we found that we also had pre-emergence dampening off as well as seeds rotting in the soil. As Emerson mentioned, the original Intercontinental Rubber Company nurseries at Salinas were on rather heavy, poorly drained soil. During the rainy season the nursery seeds were pretty much waterlogged. Since a desert plant does not like wet feet we had considerable nursery disease in the early seedling stage. In some of the nurseries there were many low areas where practically all of the seedlings were lost.

In terms of the overall disease picture, I think it would be well if we start thinking in terms of where and when the diseases occur and which diseases are giving us the most problems and where; thus the easy breakdown would be first, the nursery diseases, then the transportation and storage diseases, and last, what we refer to as field diseases.

When "wet feet" occurs at this stage of growth the plant just does not survive because of dampening off or pink rootrot. This name was given to the disease because the lesion on the taproot or the primary radical has a pinkish appearance. The disease is caused by Pythium sp. One of the transit or storage diseases is caused by Sclerotinia. We found that nursery stock grown on land that had a history of vegetable production such as lettuce and beans, where the soil was pretty well infested with the sclerotia were especially susceptible. When the plant is lifted and packed, particularly under warm moist conditions, the loss may be up to 100 percent. Pythium rootrot occurs where there are extended irrigation runs and where the temperatures are above 100 degrees. There will be extensive losses, particularly near the water outlet and also at the ends of the rows where the water tends to accumulate. Verticillium wilt is a very widespread field disease, particularly in the cooler valleys of California but it occurs elsewhere in the United States.

Botrytis, called grey rot, which is also a transportation or a storage disease, causes some losses in the nursery if environmental conditions are correct for disease development. Diplodia dieback, first observed in the lower Rio Grande Valley of Texas and caused by Diplodia theohromae, occurs as a lesion at the juncture of a leaf and the stem. In many cases the lesion continues to develop from the base of the dead branch completely encircling the stem of the plant, and of course the entire top dies. In the later stages of fungus development on the dead branches the fungus erupts the bark and the fruiting structures are formed. Rain and wind primarily disperse the spores.

At San Antonio in an indicator plot, we had considerable mortality from Phymatotrichum rootrot. Phytoptlora will also take out a tremendous number of plants. Are there any questions?

Lobenstein: There are two questions: When you give this review of all the disease it sounds like the whole world is going wrong with diseases and there is no chance of growing guayule. How prevalent are these diseases, and to what extent can they be avoided by cultural practices?

Presley: I would say that cultural practices are helpful in reducing the overall loss from any one of the diseases. The choice of planting site is more important. I would not plant guayule in an area that is known to be pretty heavily infested with verticillium. The same thing is true of Phymatotrichum rootrot. In areas where it is necessary to prolong irrigation runs, if you could just wait until winter to irrigate, it would be fine; but unfortunately the plants like to have water during the summer too. And if the temperature is around 100° it is very bad.

Question: (G.A. McCallum) I would like to ask you if the quality of the irrigation water utilized might have any bearing on the disease problem?

Answer: (Presley) Particularly around Edenburg, in the lower Rio Grande Valley, the softest water that is generally available naturally is about 600 parts per million dissolved solids. There is a lot of calcium in the water there too and this particular near-brakish water has caused quite a bit of problems with some crops in the lower Rio Grande Valley.

Question: Do you suppose this could have some bearing on guayule?

Answer: I think very definitely that it could have a bearing on the general health of the crop. We feel that any plant that is weakened in any way, whether it is by accumulated salts in the soil or whether it is by overirrigation or by irrigation water of the wrong temperature when applied, will predispose the plant to a greater amount of loss than would be the case if not subjected to such conditions.

Question: Is it true that nothing was done toward the development of resistant varieties to any disease? The program was, I think, too short for that.

Answer: Leroy Powers and I were working on verticillium resistance when he left the project. But we didn't really get far enough to have any variety or strain that was resistant to disease. As you say, ordinarily breeding for disease resistance is a long-time project. You will recall though that selection 405 was considerably more resistant to verticillium than 593. There is a possibility of raising the general level of resistance, maybe not immunity but to develop a field type resistance. This is essentially the point I want to bring before the audience.

Comment: (W.A. Campbell) There is a publication in which they indicate a selection 111 which was very resistant to verticillium wilt. Dr. Powers and I found that to be true in the trials at Salinas. If anybody wants a copy of this disease bulletin I might point out that Bill McGinnies has an IBM Xerox copy and he might make other copies.

Bob Helgeman: I might add a comment on disease. Herb Kramer and Leonard Johnson were working on disease in the Salt River Valley and they made a planting of quite a large assortment of seed. They did manage to get, I think, a couple dozen plants to survive. Then they took seeds from these, planted them and much to their disgust they concluded it was all happenstance; they had no resistance to desiccation.

Question: (Noel Vietmeyer) You mention that some of these diseases occur on cotton and lettuce and other things. Can you give us a perspective about the general disease situation on guayule? Is it very serious compared to cotton, lettuce and other plants, or is it about the same or less?

Answer: (Presley) Sometimes spacing has a great deal to do with plant response to disease. You probably remember the work on cotton at Las Cruces on plant population and percent verticillium wilt. This was an actual reduction of the number of plants infected--not just the percent infection--but if the population of cotton plants, for instance, were raised from 25,000 to 45,000 per acre, the amount of verticillium wilt was cut in half. Some of the indicator plots with guayule suggested that this is also true in guayule because the wider spaced plants had greater disease loss than the more thickly spaced plants. However, these guayule plots were established practically under duress and the mortality was rather high in some of the plots. So when you say you have a thick population this is a relative thing. This should be kept in mind in evaluating disease response.

Question: I would like to ask if you were going to do this planting on a large scale and you had a very large area of guayule and one small portion of it became diseased, would this be a serious threat to the entire planting, or is this something that could be controlled on a local basis?

Answer: Fortunately the diseases that we are dealing with are generally not airborne, but are soil-borne, and with that in mind, to the extent that the disease itself moves through the soil--that is, the fungus--there would be no danger from an isolated spot in the field. This is not the same as with rust; if you are growing wheat and you get stem rust at one location in the field, the entire plot can become rusted from it. That's not true with the guayule diseases.

Question: (W.G. McGinnies) Your presentation was largely concentrated on the microscopic characteristics of disease rather than broad relationships. What percentage of these diseases are the results of mechanical injury or from fungi? Most of the diseases you have described are the result of the culture or mechanical handling of the plant. Is this something which obviously would be subjected to control? How about bacteria and viruses?

Answer: (Presley) I'm glad you mentioned bacteria. In California there is an area where there was considerable loss from the bacteria that, so far as I know, had not been determined as to genus and species as yet. That was generally associated, again, with over-watering and waterlogged soil. The other part of your question is that there are certain diseases, for instance verticillium, that in cultivation we have what we call root pruning. I'm sure you are familiar with the ploughs passing between the rows of plants--where the roots have gone into the center--where those roots are essentially pruned off in the cultivation operation. We find in cotton, for instance, that you have a higher percentage of verticilium wilt and fusarium wilt where this root pruning has occurred.

Question: I have one other question. I might assume that you folks at Salinas discovered all these diseases on the cultivated material, the cultivated shrub, or did they exist with the guayule while it was in its native state?

Answer: (Presley) I think the guayule in the native state is as pointed out in Lloyd's monograph, essentially disease free. I surveyed the entire Big Bend Country and did not find any disease.

Question: Your discussion concerning disease referred almost entirely to irrigated guayule. Did you find the same diseases on the nonirrigated cultivated fields?

Answer: You are familiar with Frio County, Texas. All of the guayule planted in Frio County was nonirrigated and there was one field on the Sanderson farm that had what I called canker. It was caused by Diplodia and apparently the plant was predisposed by the very high temperature right at the ground line because this is where the canker occurred. When the canker progressed around the entire collar of the plant, of course, the plant died. That is the one disease that I observed on the indicator plots at Pearsall.

Comment: (Campbell) One thing that should be mentioned here is that all the water in the world on guayule when the soil temperature is below about 65° will do no harm. Practically all the problems we had with irrigated shrub were blamed on too much water by the farmers or those acquainted with irrigated land. In other words, we were the ones that came along and put a disease tag on it. The farmers themselves all recognized too much water when they saw it.

Question: All of these diseases are widespread and appear on many different kinds of plants. They attack guayule but they also attack a great many other plants. It's the conditions under which the plants are growing that very often is important as to whether or not you get an epidemic. Is that correct?

Answer: I think that I would go along with John Emerson on this point and also to allay some of McGinnies's fear that all guayule is going out the window. The diseases are the same on guayule as they are on corn, turnips, alfalfa; it's a portion of the field. And to the extent that you lose a portion of the field depends on the size of the field as to how much loss it is to you.

REVIEW OF WORLD WAR II EXTRACTING AND PROCESSING GUAYULE RUBBER

James J. Byrne
In Charge of Extracting and Processing, Emergency Rubber Project

I have been invited here to discuss the extraction and processing of guayule rubber during World War II. It is a great pleasure to do so as I recollect the many wise, dedicated and friendly people with whom I was associated on the Emergency Rubber Project. As head of the engineering operations of the Project I was responsible for the design and construction of a wide variety of facilities. I was also given general supervision over matters relating to the extraction of rubber.

In this latter capacity I participated in a committee headed by Dr. William G. McGinnies, which reviewed and approved plans for research activities and evaluated research results. I acted as chairman of a subcommittee on extraction research and studies.

In this discussion I will try to avoid repeating information which has been covered in other discussion. However, I will mention some matters presented elsewhere, in a general way, to properly place them in the context of this discussion.

Guayule rubber is chemically identical with Hevea rubber in that it is a cis-polymer of isoprene. However, it differs in molecular weight, being somewhat lower and, milled commercially by the pebble-milling process, has a higher percentage of impurities. The rubber extracted by the Emergency Rubber Project analyzed as 70.1 percent hydrocarbon, 23.9 percent resin and 6.37 percent insolubles. Hevea smoked sheet contains about 93.3 percent hydrocarbon.

During the World War II years about 16 million pounds of pebble-milled crude guayule rubber was produced in Mexico and the United States. The U.S. production was approximately three million pounds. The U.S. production was mostly from cultivated shrub; however, about 500,000 pounds of this amount was extracted from wild shrub gathered from the Big Bend area of Texas.

Two of the main uses of guayule rubber during World War II were for the inner ply of heavy-duty truck tires and for compounding with Buna-S synthetic for making the sandwich material in bullet-proof gas tanks used in war planes. The reason for using guayule in the inner ply of heavy-duty tires was that the synthetic rubbers then available had too much heat buildup due to hysteresis. For the sandwich for gas tanks, it was found that 20 percent guayule rubber compounded with 80 percent Buna-S gave equivalent swelling performance to the 100 percent Hevea previously used.

Our head of rubber extraction on the Emergency Rubber Project was George W. Miller. He was formerly a head of the reclaim division of Firestone Rubber Co. in Los Angeles and was a highly qualified rubber chemist. Due to his familiarity with other rubber chemists in the California industry we were kept informed of problems in the use of synthetics and the possibility of solving these problems by using guayule rubber. George himself developed many combinations in the experimental laboratory of the project. There was no question that Buna-S, a copolymer of styrene and butadyene, was a big headache. The tensile tests were low and very erratic and there was a high percentage of rejects in tires made from Buna-S. Late in the war, a National Rubber Co. rubber chemist reported that he had been able to raise the average tensile strength considerably by using a master batch of rubber loaded with carbon and other compounding ingredients and then diluting this batch with additional Buna-S to obtain the desired proportions. Miller tried the same thing using guayule as a master batch and adding Buna-S. The result was a tensile strength about twice as great as from Buna-S alone. Miller reported this work to his acquaintances in the industry. Unfortunately, there was not enough guayule to supply this use. I mention this here because most reports I have read on the potential use of guayule neglect to mention the combination of guayule and other rubbers. Miller was convinced that the capacity of a plant using synthetics could be greatly increased by using guayule for "master batching."

I mention the foregoing uses and potential of crude guayule rubber because the question arises as to whether the resinous rubber produced from guayule by the pebble-milling process is good enough to find wide markets or whether a better guayule rubber needs to be made. You will hear from Eleanor Taylor about guayule rubber of lesser resin content. There are other processes, never suitably explored, that will give a product approaching Hevea in properties. To understand this potential we need to describe how rubber occurs in guayule.

The guayule plant, both top and roots, contains rubber dispersions in the cells scattered throughout the plant. These rubber dispersions contain polymers of the same monomers that constitute Hevea rubber. If there were some way to extract this rubber without coagulating this dispersion, a latex similar to Hevea could be obtained. This was actually done at pilot plant scale on the Project but unfortunately

only 30 to 50 percent of the total rubber hydrocarbon in the plant was obtained. The problem was that of keeping the rest of the rubber from coagulating. Step-milling was considered but deemed unfeasible for reasons I will cover later.

Without going into detail of the reasons for the conclusion, we were convinced that recovery of coagulated rubber could be increased if the rubber in the cells was fully coagulated before the plant was crushed or cut. Such dismemberment of the plant before coagulation would result in smears of the latex on the fiber material and thereby rendering it unrecoverable. Also if drying were done after comminution the exposed faces would be overdried and rubber deteriorated.

The consensus of people with experience in guayule production was that the rubber in the plant could be deteriorated by exposure to the sun for a long period.

The extraction method which had been adopted in the guayule industry was called pebble-milling. The process included some method or methods of coagulating the rubber in the cells followed by comminuting, crushing, pebble-milling, flotation which caused rubber and cork to float and the bagasse to sink, subjecting the floating cork and rubber to heat and pressure to waterlog the cork, flotation again to float the rubber and to cause the waterlogged cork to sink, scrubbing the rubber agglomerates, drying and packaging for shipment.

The success of the pebble-milling method was partially the ability to cause the small rubber particles to unite to form large enough agglomerates, thereby improving flotation and lessening the possibility of loss in screening processes. Also the larger particles would be easier to dry in the driers where the thru-flow of air was important.

Now to look at the shrubs available for milling: Among property acquired from the government from the Intercontinental Rubber Co. was a 600-acre field of 13-year old, dry-land, cultivated guayule near Salinas, California. The early plans of the project included milling out this shrub as soon as seed had been collected from the Arguello plants. It had been estimated that the seed available would be enough to plant about 60,000 acres of guayule. However, an improved seed harvester, developed by the Project, enabled the collection of enough seed to plant 200,000 acres. Long-range plans were then made to acquire lands for planting this acreage. Later, due to a decision by Rubber Director Jeffries, the expansion of the project was curtailed. This curtailment occurred in April of 1943. At that time over 12,000 acres of field had been planted in the summer of 1942 and 56,000 acres had been leased for planting during the next season. In addition, the project had established about 3,000 acres of nursery.

Later the Rubber Director advised the Secretary of Agriculture that a certain amount of the acreage already acquired should be planted as an insurance in case the synthetics failed to fill the needs. The Project then proceeded to plant 30,000 acres of field and about 2,000 acres of nursery to be held available in case of emergency.

Now to get back to milling: Even before the curtailment of the Project, the Spence Mill near Salinas was operating on shrub from the Arguello field. This mill had been operated for a few months each year before it was acquired by the government from the Intercontinental Rubber Co. That company which was operating three mills in Mexico at the time loaned us Daniel C. Cooley who was operating their Satillo Mill and who had formerly operated the Spence. With his help and advice the Spence Mill was altered with the following improvements:

a. A warehouse was built to hold 400 tons of baled shrub which allowed about a 15-day storage before milling. It was contemplated that the shrub would be baled in the field, after about three days of exposure in piles.

b. The roll-type crusher which had formerly been used before shrub cutting and drying was moved to the milling circuit following the comminution and drying.

c. A rotary cutter replaced the ensilage chopper formerly used by the company. This was soon abandoned in favor of a hammermill.

d. The crushing line, with the movement of the bull-crusher in series included three crushers.

The Arguello field yielded approximately 2,300 tons (moisture-free basis) of shrub from which 880,286 pounds of crude rubber were extracted. The hydrocarbon in this shrub averaged 18.91 percent. The milling efficiency on a hydrocarbon basis was 90.84 percent. This milling period was begun in March, 1943 and terminated in July, 1943.

After the curtailment of the Project, Rubber Director Jeffries was told that, if the Rubber Reserve desired and paid the costs, we were prepared to harvest and mill wild shrub from the Big Bend area of Texas. He agreed.

The Texas shrub was baled on site and shipped by rail to Salinas. The total weight processed was 1,700 tons (moisture-free basis). The crude rubber recovery was 510,000 pounds. The average percent hydrocarbon in the shrub was 12.3 percent. The extraction efficiency on hydrocarbon basis was 87 percent. The milling was commenced in October, 1942 and terminated in April, 1944.

It should be noted here that these millings resulted in large agglomerates of rubber which were easily recoverable in the process. The word "worms" was used to describe these agglomerates. Our pilot plant experience indicated that it was very difficult to get large worms from young shrub.

The decision having been made to prepare to build a new mill at Bakersfield, four firms were selected in January, 1944 and invited to enter into competition by drafting their ideas for mill design. They were furnished with a prospectus and invited to observe the operations of the Spence Mill. The prospectus included new concepts resulting from research done by the Bureau of Agriculture and Industrial Chemistry and by experience gained by operations at Spence. After review of each sketch plan, the Southwest Engineering Co. of Los Angeles was selected to do the design.

One of the major innovations proposed in the new mill was to parboil the shrub, to loosen leaves, after which the leaves would be separated from the plant and wasted. It had been found that the leaves, which contained no rubber, constituted from 20 to 30 percent of the total weight of the plants. By their removal the percentage rubber in the residual plant would be increased. Also, there was some evidence that the milling leaves interfered with the agglomeration of rubber particles. Another major innovation was the use of continuous-belt driers for drying the rubber.

Rectangular, in-line, flotation tanks had shown promise in pilot plant operations so they were adopted in the new design. The theory of flotation was that, if the diluted slurry was given horizontal impetus at the surface of the tank, the rubber particles would have a better chance to surface.

Since analysis had shown its feasibility, the new design would burn the bagasse as fuel for steam production.

In June, 1944, it was decided to purchase equipment. Most of the major items were secured from a firm specializing in rebuilding second-hand equipment. Some new equipment was purchased also.

In fiscal year 1945 funds were provided for the construction of the Bakersfield Mill and the reconstruction of Spence Mill along the same lines. A flow diagram of these mills, as modified is shown in Figure 1. The schematic diagram of the power plants is shown in Figure 2. In order to get as much experience as possible, (1) For drying rubber, a single-belt, multi-stage drier was used at Spence and a two-belt drier at Bakersfield, and (2) For dewatering bagasse, a Bird centrifuge was used at Spence and an Oliver filter at Bakersfield.

The remodeled Spence Mill was put in operation in December, 1944 and the new Bakersfield Mill was started in May, 1945. Both mills operated satisfactorily until the project ended. The mills operated on young shrub (two-to three-year-old) from plantation and nurseries.

The total crude rubber production of the Project approached three million pounds. The table, page 49, shows a record of results of all millings.

George Miller's final report analyzed the results of milling. He concluded that, if rubber in the shrub is less than two percent, no recovery of rubber can be expected by the process used. He also shows that the efficiency of milling, expressed in hydrocarbon, is related to the ratio of rubber to fibre in the shrub. He reasons that the more fibre the less is the opportunity for small particles to meet and become agglomerated with other particles to form a worm that is large enough to be recovered.

Miller also emphasized the importance of crushing. He cites an experiment by BAIC in which eight passes through a crusher agglomerated the rubber sufficiently so that it could be recovered in the laboratory by merely agitating the pulp in water. However, this test indicated that repeated crushings tended to cause more nonhydrocarbon materials to be incorporated into the rubber. He felt that at least three crushers should be used in future mills.

Miller was of the opinion that the weakest part of the milling process used was in flotation. He felt that some form of centrifuge would be more desirable than flotation. He based this opinion on theoretical analysis of the flotation process as well as on experience at Spence where the Bird Centrifuge effectively separated small rubber particles from the bagasse.

At this point I will go backward in time to complete this account of rubber extraction. Early in 1945, it had become apparent that the natural rubber supply had become depleted and that synthetics could not fill the bill. Rubber Director Jeffries was quoted as saying that he was sorry that he had put the brakes on the Guayule project. The Rubber Reserve asked the chief rubber chemists of all major companies to visit the Project and appraise the possibility of rubber production from the shrub already planted. They visited the Project and recommended that the

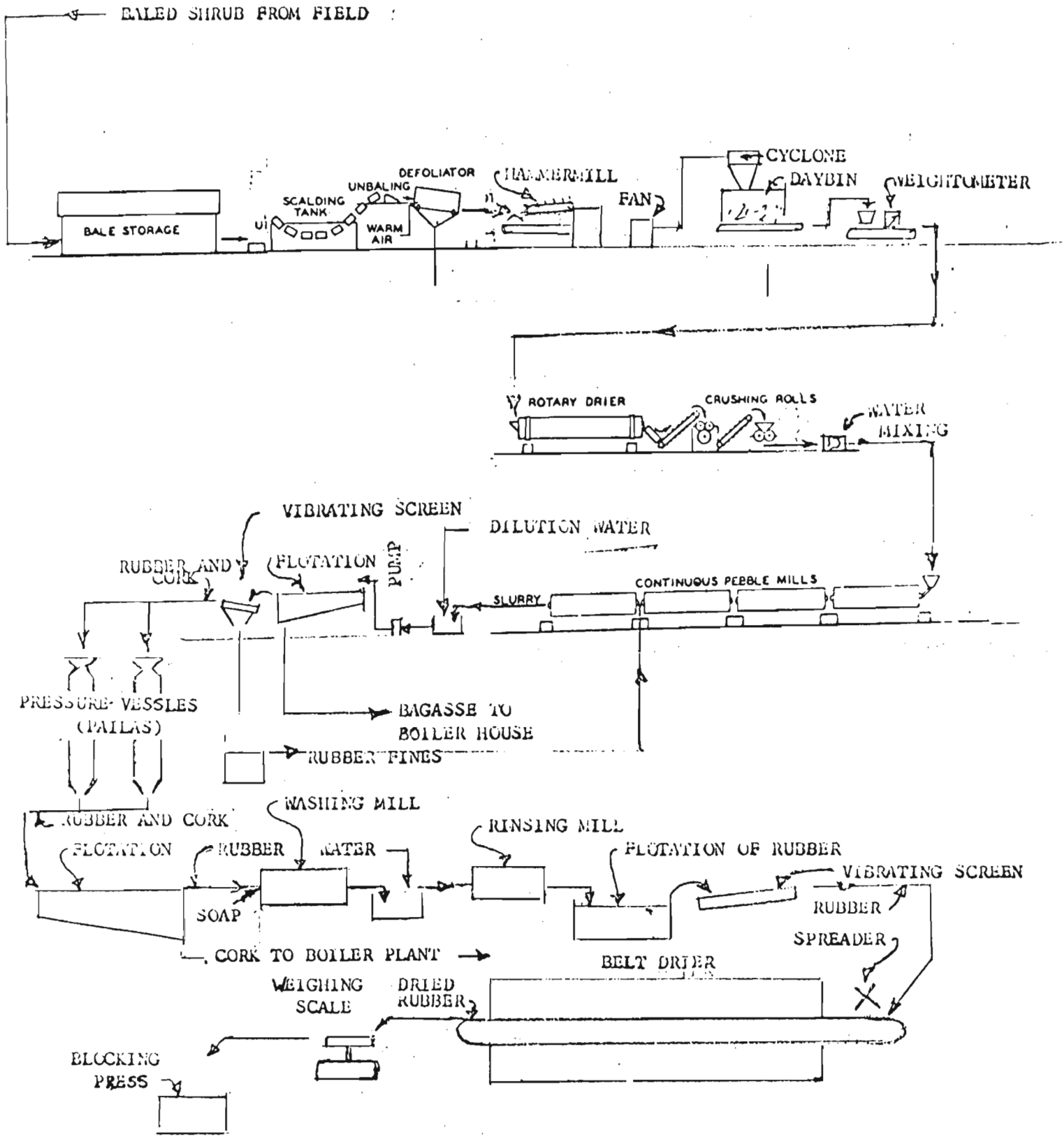

Figure 1. Flow diagram of milling of young shrub at both Spence and Bakersfield Mills.

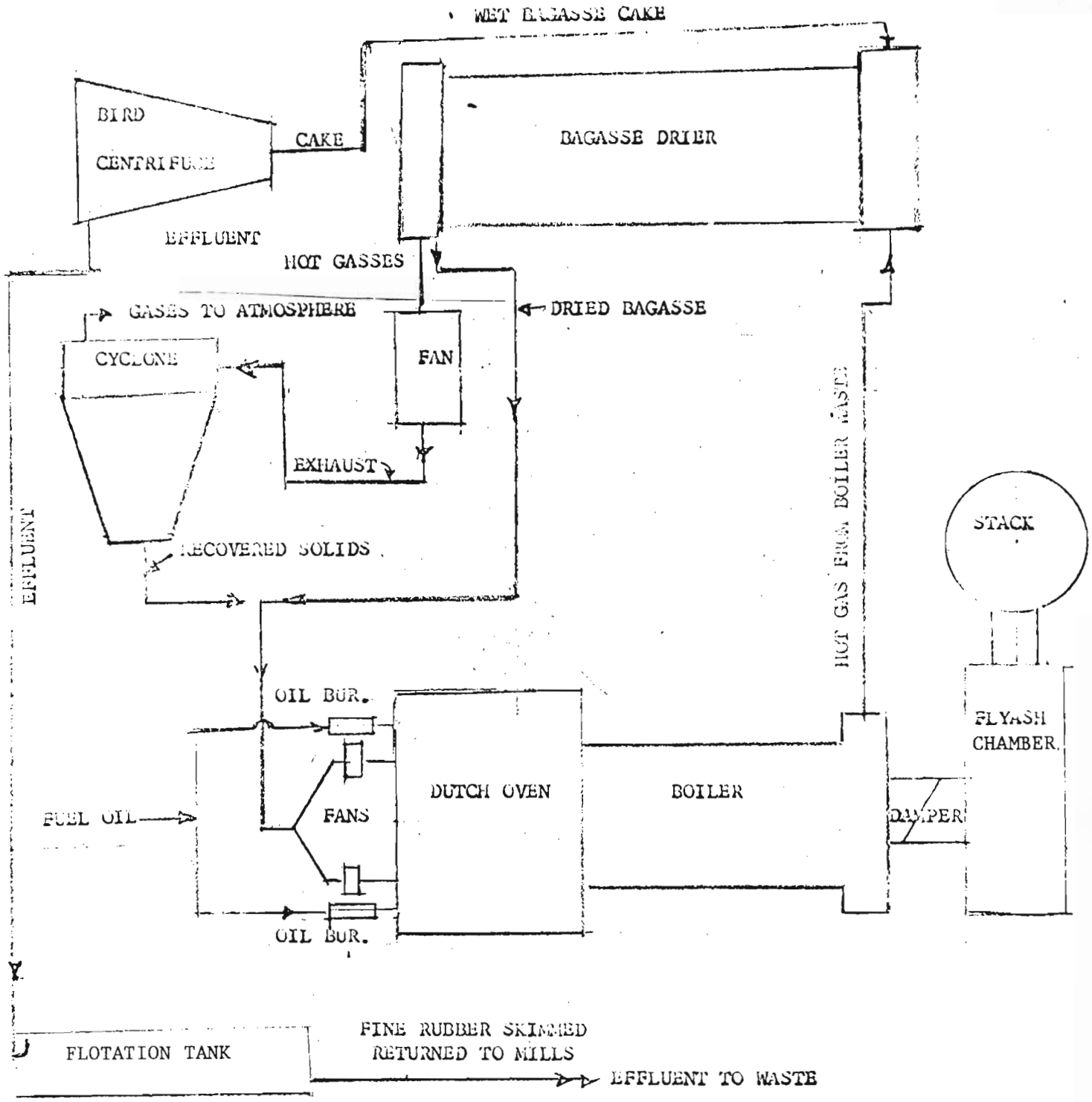

Figure 2. Schematic diagram of bagasse-burning system during the milling of young shrub.

SUMMARY OF RUBBER PRODUCTION
ALL SHRUB**

Campaign	Shrub Processed Pounds	Rubber HC in Shrub Percent	Rubber HC in Shrub Pounds	Rubber Produced by Mills % Crude	% H/C	Pounds Crude	Pounds H/C	% Recovery
Spence Mill								
Arguello	4,642,802	15.18	704,600	18.91	13.79	880,286	640,050	90.84
Texas	3,395,122	12.32	418,104	15.02	10.72	510,086	364,030	87.09
* 1945	7,125,191	8.15	580,745	8.70	6.15	620,217	434,969	74.91
* 1946A	3,207,513	8.18	262,375	9.37	6.55	300,510	210,031	80.04
* 1946B	2,588,538	7.93	205,171	7.17	5.12	185,590	132,520	64.59
**								
Bakersfield Mill								
* 1945	1,352,191	5.93	80,212	4.21	2.96	56,800	39,946	49.80
* 1946A	3,315,184	5.14	170,400	4.32	2.98	143,310	99,173	58.20
* 1946B	3,304,839	6.88	227,373	6.16	4.28	203,430	141,452	62.15
Grand Totals & Averages	28,931,380	9.15	2,647,940	10.03	7.13	2,900,229	2,062,171	77.87

* Young shrub.

** Eliminated from consideration in this report is the rubber produced at Spence Mill during the period December 2-14, 1945, since this involved experimental Jordan milling and the resultant data are not amenable to the analytic method developed in this report. Total rubber production by the Project, including that produced in the experimental laboratories and in the experimental Jordan milling at Spence Mill, was 2,944,909 pounds.

Forest Service proceed immediately to build four additional mills to process the shrub in the ground. However, the Forest Service Chief would not accept the responsibility of processing the shrub. Firestone Rubber Co. was then given this part of the rubber production job.

Later, in June, 1945 the Rubber Reserve called a meeting in Akron, Ohio to discuss the situation. Present were the chief rubber chemists of the larger companies, BAIC researchers, George Miller and myself. The purpose of the meeting was to firm up the process to be used by Firestone. Some of the findings were:

1. Firestone would proceed with a design along the lines of the mills already in existence but would improve the flotation process.
2. The BAIC was asked to continue, at an accelerated rate, investigations of retting and certain other milling processes.
3. I was given the task of getting the machinery and setting up at Spence full-scale equipment to test Jordan milling and controlled retting of shrub particles.

We were told that nothing should stand in our way, that we had the highest priority to equipment and materials. To make a long story short, I was able to arrange for: (1) The Noble Wood Machinery Co. to supply three large Jordans immediately and send a pulping expert to Salinas to help in their installation and test, and (2) A second-hand trommel type drier from an abandoned cement plant was purchased and put on its way with priority routing.

Experimentation with a small, laboratory-type Jordan, in batch milling had shown rubber recoveries of about 90 percent. Also the rubber had less insolubles.

The Jordan machine (see Figure 4) is a device used in the pulp and paper industry to defiber wood pulp. It consists of a rotor shaped like a truncated cone and a stator shaped to receive the rotor. Bars with wooden separations are arranged around the periphery of both rotor and stator. The gap between rotor and stator can be varied by moving the rotor in or out. The defiberizing and cutting process is accomplished by injecting the slurry in the small end and subjecting it to constantly increasing velocity, turbulence, and cutting action as it passes, through the gap, to be ejected at the large end of the machine. A combination of rubbing action, turbulence and cutting can be varied by change in the gap or in the depth of slots between bars. The time through the machine can be varied by a throttle at the outlet.

The Project was terminated before the Jordans were fully tested and before the retting cylinder was put in operation.

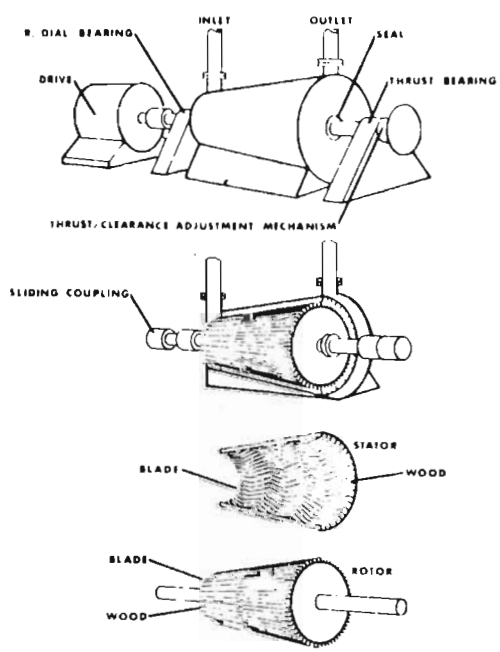

Fig. 4. The Jordan Refiner

Another item of interest was that mill scale experiments of bale retting were carried out at the Spence Mill by the Forest Service in cooperation with BAIC. The bale retting of parboiled and deleafed, baled shrub was shown to be successful and practical. The effect of retting will be discussed later by Eleanor Taylor.

I also will add that the extraction of rubber in a dispersed state from the shrub was accomplished by BAIC in pilot scale tests. The latex approached Hevea in quality. However, the maximum recovery was only 50 percent of the hydrocarbon available.

Other pilot scale methods of extraction were carried out. One, the digestion of shrub by sodium hydroxide before milling was considered undesirable on account of the difficulty of removing the sodium hydroxide. The resultant rubber had short shelf life. Another experiment found wanting was the coagulation of rubber by the introduction of acid in the milling process. This also was found to be impractical.

A promising process to recover deresinated rubber is that of extraction using a solvent such as acetone or alcohol. This was not sufficiently tested before the end of the Project. However, the process has been demonstrated to be successful in drying wood.

I will conclude this paper with a quote from the Miller final report: "In closing, we feel that work done so far to improve the mechanical extraction of rubber from guayule has barely scratched the surface. In our work to date--to paraphrase Isaac Newton--we have noted and examined only a few of 'the brighter pebbles on a mighty beach.'"

Questions and Comments from the Audience

Question: (E. Campos) What amount of moisture would you get?

Answer: (J. Byrne) In our process we dried, baled and cut it, then dried it further at the entrance to the dryer. At Bakersfield it ran about 25 percent moisture content and at the outlet it ran from 12 to 18 percent. It seemed to be satisfactory.

Comment: (K. Taylor) If there are no more comments on Mr. Byrne's paper, I have one comment to make. He noted that the younger shrubs were defoliated to avoid overloading the mill with about 20 to 30 percent of unproductive bulk. There was another reason which perhaps was not evident at that time but became evident later. The leaves contain the major portion of the metallic constituents of the guayule plant. They contain appreciable quantities of iron and certain amounts of copper. Both of those metals served as antioxidants and there are other materials in the residue which serve as catalysts to oxidation, so we found it advisable to remove the leaves as a source of metallic contamination in addition to reducing the load in the mill. It is the copper which is the real bad actor promoting the deterioration of crude rubber.

Question: (C. Pardo) You mentioned earlier compounding of the guayule rubber with Buna-S up to amounts of about 20 percent. Does this contain the resin or was this deresinated guayule?

Answer: (J. Byrne) This was the resinous variety. Actually, you have to remember that until 1910 most of the rubber used in tires was guayule and the company had one of these old tires down there; I have a picture of it.

Question: Is there any published information on this?

Answer: (J. Byrne) In the Emergency Rubber Project they were too busy getting things done to write papers. The only things I know that George Miller has written on this were personal notes to certain rubber chemists telling about the results of his work. He never published them.

Question: (J. Bonner) Do you have information somewhere written down on yields, tons per acre and pounds of rubber per acre from all the different individual campaigns that you carried out, or was all that information accumulated in the full investigation?

Answer: (J. Byrne) We did not publish the information we had but at the time we decided to mill out all the rubber--as much rubber as we could in a short period of time. We made an analysis of what we could actually obtain. We used the best information we had and I have a copy of that; if you'd like it, I'll send it to you. It appraises the amount of rubber in all of our field plantations as of that time which was about a maximum of three years old.

Comment: (P. Allen) I'd like to add to Ken's remarks about the leaves. I think that the removal of the leaves also removes a lot of resin.

Comment: (K. Taylor) That is correct, and bear in mind that if resin will become a by-product then it might not be desirable to remove the leaves.

Question: (H. Lobenstein) Jim Byrne mentioned the Arguello field. He corrected me; I thought it was eight years old but he said eleven. I guess that is correct. Can we not conclude that that field had passed its ultimate, that it was going down?

Answer: (K. Taylor) That is correct, and it was not due to the fact that the rubber itself had deteriorated in the plant. But the plants had lived there long enough and had been subjected to a certain amount of mechanical damage by cultivation. There was a certain proportion of dead material in the shrubs and the dead material contained a certain percentage of rubber. The quality of rubber in the dead branches was not as good as that in living branches, so it had passed the peak. It might not have done so under wild conditions where the mechanical damage had not occurred.

COMMENTS ON RUBBER EXTRACTION AND UTILIZATION

Sidney Kalver
Rubber Extraction Equipment Studies, Emergency Rubber Project

At this point I want to pick up some of the things that were done in the Bureau of Agricultural and Industrial Chemistry Pilot Plant. The purpose of our studies was to try to improve some of the deficiencies in the operation that were obvious at the time. You have heard the discussion of most of these but I would like to emphasize some of the details.

A paper cutter was originally used in cutting the shrub and later they used a rotary cutter. Because of sand on the wood and the presence of bolts and even hay forks in the bales, breakdowns on the knives often occurred and the maintenance was great. This acted as a stoppage for the entire milling operation. Ken Taylor suggested the use of hammer mills and that happened to be one of the greatest improvements because hammer mills require practically no maintenance. A whole bale of 145 pounds or so could be pulverized in a minute or two to the size wanted in a single pass. In three or four hours the hammer mill had ground up enough shrub to keep the plant running for a day. That was one step.

The next step was the introduction of the rotary dryer to dry the pulverized shrub. This helped in the coagulation and therefore in the yield of rubber by reducing the moisture content. Uncoagulated latex has a tendency to disperse in the water and go out with the effluent. In pebble milling there is a cylinder with open trunions at each end. The cylinder is lined with flint blocks and is kept approximately one-half full of flint pebbles. These are hard materials and they prevent the metallic contamination of the rubber since there is no contact with the steel shell. The pebbles, as the shell rotates at a speed of approximately 75 percent of its critical speed (critical speed is the speed in which everything would tend to stay centrifugally in contact with the shell and not cascade, such as you get in a spin dryer) reach a peak. If you go too slow you get no cascading or if you go too fast you get no cascading. So 75 percent gives about the peak of cascading and action with the greatest effect of weight and rubbing action. You get a rubbing, shearing and an impact that breaks the cell further, smears the rubber and tends to build up the particles into what are called worms which are really like a sponge. There are particles touching particles with air spaces between them. If you obtain the proper size of these particles, with a limited amount of tack, you get an easy flotation separation and a minimum adherence of the impurities or insolubles to the rubber. That gives the cleanest rubber with the best yield.

The pebble mill has its limitation; it is bulky. As a result Jordan mills developed by the paper industries were considered. The idea was very similar to guayule processing; that is to spread the fibers, separate them and hydrate them, and release the lignin and other materials so as to get a strong paper. One of the problems with the waste material was that the fiber was considered too short for many paper applications. I think that if we consider Jordan milling we might not have to cut the fibers that short; therefore at the same time we are releasing the rubber we will be preparing the fibers to be used as a paper. So that might be a very good factor and by-product application. When we did the Jordan milling we had a problem there. Jordan mills have been developed more or less in an empirical manner in the paper industry. At that time, and I don't think even at this time, there's very much theory analyzed in the Jordan as to quantative results. It's really just a trial-and-error arrangement. We weren't satisfied with that. We started analyzing the results we had and we found that we could set up a parameter

which we called potential cuts per ton. We analyzed the length of knife blades, in the shell and the total length of knife blades in the roller. In every revolution we said, "These number of inches of knife will pass these number of inches there, and there is the equivalent number of cuts that you would get with a scissors for every revolution." If we took the number of revolutions we exposed the shrub to, and the number of pounds of shrub per hour going through that mill, we had a potential number of cuts per tonnage of rubber. That was a unit of measurement that we could use to compare the results. So we started with that. Then we found that reached a certain peak production after we had several methods of getting our yield, both by the rubber that went into the effluent and into the underflow of our flotation, and the recovered rubber from the actual flotation of the rubber after it left the mills. We plotted these and we found that after a certain point you didn't get any increased recovery. At some points you get a decrease in rubber yield. We started anaylzing it and found we were getting two actions there: a cutting action that releases the rubber, and a rubbing action as the blade passes over the blade that smears it and causes these particles to build up into worms just as in the pebble mills. These are two independent actions. After you get to a certain point and keep on cutting, you might be reducing the particles so that you didn't get good recovery; if you rubbed it too much you might be wiping in the fibers that would weigh it down so that it wouldn't float. We analyzed the other (the rubbing action) and figured it by the thickness of the blade, times its length, times the area of the blade's surface which gave us square inches which would be the rubbing action. So we analyzed what would be the best return for the yield, based on the square inches per ton, and what was the best on linear inches per ton. Then we reasoned that if we were to combine those values in our mill that we built for the plant, that would give us the combination that should be optimal.

We then worked back; using the square inches and the linear inches--working back to the bottom--we got the thickness of the blades. Now we were able to say to the manufacturer, "We feel we need a mill that has a potential to give us (so many) inches of blades and (this) thickness of blade," and that we were able to fit it to specify the type of mill, the size of mill and the type of knife arrangement that would do our job. That was how the order was placed. When the end of the pilot plant work was approached, we didn't do too much more on that but we did set up and that was the base, I believe, that was used in the mill. That was one step.

No one has mentioned the flotation. There is a big problem in handling the guayule rubber because of the worms that are soft and can't stand mechanical handling. They'll squeeze together; they'll compact to entrap fibers that can't be released. Secondly, water is entrapped that can't be dried out because one of the properties of rubber is that it's waterproof. A shell of water is formed if you put a raincoat or a balloon around it. You can't get that water out unless you heat it enough to explode it so that the balloon is burst. That was another problem. Therefore, the worms had to be handled carefully. One of the ways we worked in the factory was using airlifts. That's a very simple approach. We also used steam jets for mixing. In the pilot plant we made up our own mixes which was a variation of a steam jet injector--a tee with a nozzle which let in live steam and sucked in the fluid from the side branch of the tee. It was then pushed out as a mixture of steam and water and rubber. We also used airlifts for the raising in the flotation tanks as it came out and went down to one level. When we wanted to pick it up to go to the next flotation tank, we formed a column and by injecting bubbles of air at the bottom, at a very low rate, we created an apparent specific gravity change that would raise that column by a certain

percentage over the regular level and that was enough for the lift. In other words, if we wanted to raise it two feet if we had a pond, a sump that would be four feet deep, just a little aeration would change the apparent specific gravity so that it would balance the four-foot column of water on one side and would balance the five-foot column on the other; there was an overflow to the next tank. That is what we did at Bakersfield.

The flotation that we had at Spence was a different arrangement. We had a rotating pipe that fed the worm slurry over the top surface of the vertical cylindrical flotation tanks. As it came out, it had a sweep in front of it and it kept sweeping everything that was floating on the water ahead of it until it came to a radial trough where it put it over the end. It overflowed and came out the side of that radial trough. In the meantime, we had spread a layer of worms behind it as it went around. On the next revolution it would sweep those floats ahead of it and deposit another layer behind it. We felt that we had a much better control over the flotation with a rectangular tank because we could choose our own parameters of width, depth and length to suit our needs. That is what we did at Bakersfield.

The next big change was the cooking; we had a problem there. We're doing a physical separation and it's all based mainly on specific gravity. When it was milled you had a woody material, rubber and cork from the bottom layer. In the first flotation, the woody material was heavy and would sink, but the cork and rubber would both float. The first flotation, therefore, took off a mixture of cork and the rubber particles. In the old plant they used a pila which is a cook and pressure cooker. They sewed it up and ran in on an 80-minute cook, I believe, and something like 60 to 80 pounds of pressure. Two hundred pounds? That was 200? O.K. Anyway, it took an 80-minute cook and then we would release the pressure at the bottom. Suddenly we would be fully warm while the others cooked. We had two pilas and we alternated them. We released the pressure suddenly and got explosions really like puffed rice and things like that. The corkshells which had been saturated with the water under pressure suddenly exploded. They were waterlogged to start with and became an explosive besides; therefore, the cork would now sink and the rubber could be skimmed off with very low cork remaining. Any woody material that had a tendency to float before would now be waterlogged and would also go down. Until you got to the pila, everything was cold; you had about a four or five to one ratio in the mill. Then you skimmed it off, dewatered it, ran it into the pila with fresh water and cooked it. It came out hot; you diluted it from that flotation tank with as much as twenty to one, I believe, going through the scrubber which was another short pebble mill that would now be hot. We also experimented with the use of detergents to help scrub it clean. Here you had a dilute hot milling which knocked off any adhering particles and the flotation would drop back. Then we would dewater it and take it into the dryer.

The dryer was the next big innovation. The old Spence mill used vacuum shelf dryer. Vacuum shelf dryers are big and cumbersome, and of course, relatively difficult to get during war time because they were big castings. You had to load these trays. They had a mechanical loader but still it was quite a problem--you had to get them uniformly and then put them in the dryer. They dried it under vacuum for three hours, then opened the door, released the vacuum, and the plant superintendent took out a handful from various points of the tray. If it didn't have any green spots in it, smelled all right, wasn't over-cooked, wasn't too wet, that was a finished batch. If not, it went back and the vacuum was put on for perhaps another hour. That's a bottle-neck in a plant of this nature, particularly

when you want to increase it. At this time the synthetic rubber program came in and it was based on continuous apron through circulation dryers. These are perforate flat aprons that are piano hinged and they traveled through a heated dryer where there was a circulation of air down through the bed of material, and recirculating heated air which would evaporate the water. The synthetic rubber was not tacky. It was very firm; it was also milled out, and they got it into pellets. There maybe they would be able to torch it. Therefore they worked out a system of multi-belts; the first one they started at higher temperature, got off the surface water, heated it all up, then they piled it on another apron twice as thick by slowing down the belt. There it resided for a longer period of time, in a thicker layer, and was subject to the air to evaporate the moisture at a lower rate to take more time to come out of the interior. Then the third belt was piled maybe four times as thick because that was running half again as long and fast. Therefore you had residence time twice as much on that belt; that way they got a long residence time and the rubber was not affected after all this. The only thing the heat did was perhaps soften it up a little bit and make it better for milling. So they didn't mind it and that was the system used.

Guayule couldn't stand that although they tried to do it because we had another problem. We had resins in that rubber. We had two sources of problems there. If you had too much water on the rubber as it went into the dryer you had solutions of resin on there and that would coat the dryer as it hit the apron, and it formed a sticky layer on the apron. If you overheated the rubber you would have some of that resin softening and exuding out, and that would tend to seal the pores; it would overflow and seal the interstices between the worms so that you didn't get air flow going through it. That part that was sealed wouldn't dry properly and you would have green spots as it came through. The solution is transferring it while it would break it up and open it up to expose it on the surface. At the same time you're pinching off parts just where they're soft and where they are tacky. You seal where the resin is and that would hardly ever dry on the next belt. We thought we should go back to what the vegetable people had found in the past. They had case hardening. They had certain vegetables that were sensitive to drying. If they dried it too fast, they formed what they called a case hardening shell which sealed off the pores and trapped the moisture inside. We approached it from the other end; we started with a low temperature on the first belt. There is no point in taking away all the water on the surface faster than it could come out from the interior. You're going to have to wait for the water to come from the interior anyway. In the long run it has to stay in the dryer long enough for the last drop to come from the center of the worm for the surface to be evaporated. So what's the hurry in getting it off the surface; you might as well keep it moist, pliable and available. We started with a lower temperature but producing a lower evaporation rate at the early point. Before we got very far we found that our drying cures crossed one another and by this point it had caught up. Not only that; it surpassed us and we ended up with a faster dry by increasing our temperature gradually.

We had another advantage, the resin; since the rubber didn't reach the dry bulb temperature, it was always at the wet bulb, or close to it. We had a cooler rubber and we never caused the resin to melt and exude. We ended up with a nice spongy porous mass that had a good tensile; we had to rip it apart at the end. It was almost like a washing sponge--the rubber sponges that they used to make. This ended up with a nice uniform color all the way through, and a good rubber at a very rapid rate of drying. We found that very successful.

Parboiling was introduced and tested along with defoliation, rebaling and storage. We found that the storage was a little bit more uniform. You had to

keep a certain amount of storage because some days you couldn't harvest in the field because of the rainy weather; therefore, we found that we averaged out about 30 days' storage. In the end they might have found that not too good, but that's what we started with. We didn't go to ensilage storage; we stood it in the bales, then we changed. We didn't use the rotary cutter for the primary cutter; we ended up with the hammer mill. We did go to the screening and then to the subsequent crushing, and this was the forerunner of the Jordan mill.

There are other hydro-pulpers and other pulping mills of different types and some of those might even be more desirable because of the improvement in technology in the last 30 years. We should really eliminate the pebble mills.

The flotation packs stayed with us. With regard to flotation, we did try using the bird centrifuge for flotation in the pilot plant. We had it before it was used on the bagasse and at that time there was no suitable means of discharging floats from the bird centrifuge. There are some modifications that might be possible now, but I don't think that centrifugal force is really desirable.

We tried a twin apron dryer but the thing we predicted in our pilot plant studies showed up in the twin aprons that we used in Bakersfield; the Sargent single apron that we had in Spence was always much more effective and more uniform in its output, handling various types of materials. Instead of using the press rolls on the Oliver rotary vacuum filter, we found that there again the pressure and the harsh treatment did not improve the drying. Over dewatering was not necessarily a benefit. You wanted to just get the surface water off and we found that a gentle vibrating screen was better for that purpose. When we had difficulty in grabbing at the handle (such as the Jordan mill's fine worms) we found that by putting a second deck on top of the screen, a cross mesh about a half inch or 3/8 mesh up there, it would tend to spread it so that it didn't lump up, and uniformly load the vibrating screen so that it came out as a dry fine set of worms that could then go on to the dryer. I think that if you end up with worms by any of the new methods, you will not necessarily have a problem with the apron dryer. You can load the dryer to give you the same pressure drop through the bed so that you can get a reasonable air flow. We found that about 300 linear feet per minute going through the bed was an effective velocity. If you adjust the loading to maintain that kind of float through the bed, you can then, in order to get that light loading, be speeding up the belt. I think you will end up getting nearly the same output out of the dryer because you'd have bed drying at a rapid rate and the belt will be moving that much faster. With the method of handling on the vibrating screen, I think that you will not necessarily have any problem there.

This is a sketch of our rectangular flotation tank.* This was the preliminary for the ones that were finally put into Bakersfield. The revolving skimmers are at the end; the drag pulling the sinks up the incline to discharge are at your right. This is the plan used showing two skimmers and two channels there.* This is more detail on the flotation tanks, showing some of the features we tried to put into it to handle the difficult materials.

We explored the use of a pressure cooker in the pilot plant. We used a 2,000 pound pressure and found that we could now run on a two-minute cycle. This is the preliminary sketch of the pressure cooker.* Since we were running on a two-minute cycle, the capacity was much less than the pila and we used only a single one instead of two. Therefore we had a small diameter. The feed mechanism was a

*Slides

rotating snail similar to what we used on the pebble mills. It scoops it up, takes it through the hollow trunion and discharges a fixed amount which was controlled by the level in that tank into the pressure cooker. Then we had a rinse tank which is a float-controlled tank similar to a water closet tank. That discharged enough to sluice off any worms that might have gotten stuck to the plug poppet at the top and keep the seat clean. It was designed so that the pressure on the inside acted on a larger area than on the seating surface of the valve, so that you would have it tight when the pressure was developed because you would be building up to 2,000 pounds on a short cycle and you had to keep it clean.

Questions and Comments

Question: These two talks have raised a lot of questions in my mind. If I have time I would like to ask three. The first question: The first speaker mentioned that there was six percent insolubles in the finished product. What was that material?

S. Kalver: It was primarily very tiny fragments of wood fiber plus a very little bit of rock flour, which is derived from the pebble milling operation. There was no rubber jel that we knew of in that. I might add here that in certain other operations we were able to reduce the insolubles or so-called dirt content materially.

Question: My second question: I was impressed by the complication of all of this, with the wet milling, the rotation, the high pressure cooking, etc. I know one of the speakers, talking historically, said that solvent extraction was completely impractical in about 1910, but the modern synthetic rubber industry makes polymer by pollution polymerization and they can economically handle the dilute solvent rubber, recovering and recycling solids and processing the rubber from them, etc. I wonder--for a modern process wouldn't you use solvent extraction to give you a much more simple process to eliminate this six percent insoluble?

K. Taylor: As chairman, I'm going to try to straighten this matter out the best I can. You must remember now that we are reporting what we did during World War II. It does not say what we would do today, and it is very possible with the modern techniques and modern facilities that are available, that a solvent extraction might be possible. In our own personal experience, and in our factory operations, we don't know.

Question: My last question may not be too reasonable either, but it seems as if you are going through the process of starting with the rubber in small particles and building them up, sticking them together, etc. The rubber industry at present is interested in going towards powdered process, using powdered rubber, powdered mixing techniques, powdered handling techniques, etc. I wonder if you could envision a recovery process where you use a parting agent and kept particles from the operation, obtaining a powder or a fine crumb particle?

Answer: I think this is possible and entirely within the realm of possibility, but again it lies outside of our kind of experience and our research, and we do not have a complete answer to your question.

Comment: (J. Bonner) In my other incarnation I'm a representative of the Hevea Rubber Industry. We know from rubber processing in Hevea, that the crumbs can be allowed to go to any desired size when we use castor oil. Castor oil covers the

particle and crumbs grow spots. If that were applied in the case of guayule processing, the same results can be achieved.

Question: (Emerson) Those Jordan mills that you talked about that were specially designed: How much were those used and what kind of differences, if any, in quality of the rubber were there between that and the pebble milling processing?

S. Kalver: Perhaps Jim Byrne can answer that better than I can. I'll give you a very brief summation and allow him to elaborate on it if he will. The Jordan mills that we used at the Spence mill were acquired very late in the program and it was after we shut down the seven mills. We made a very short run of less than three days, as I remember with the big mills, when we finally got Congressional orders to shut down everything. So our experience is extremely limited. The data that are available from it may not mean too much, but I can tell you this: The Jordans that we acquired at Spence mill were so huge that we did not know how, at that time, to throttle them, but there is a method whereby they can be throttled. The end result at Spence mill was the fact that we flooded the entire end of the factory beyond the mill, as we did not have flotation tanks big enough to cope with the situation. We had rubber all over the floor. We did not have dryers enough to cope with it, and it was in general a ring-tailed mess at that time. Aside from production, we were unable to get rubber of appreciable quality and lower insoluble content from Jordans when compared to that from the pebble mill. And it has always been my thought that Jordans probably would be the milling machines of the future.

Comment: (J. Byrne) I mentioned earlier that I had eight years of experience in forest products research and I'm pretty well acquainted with the pulp milling process. I'm convinced that something similar to the Jordan but not the Jordan will be the mill. You get different degrees of turbulence and things of that kind. We tried the paper end but we did not know enough about it.

Comment: (K. Taylor) Just a very brief word about latex. We did some investigations during World War II and subsequent to World War II in the recovery of guayule rubber in the form of latex. It provided a very good quality of material. It demanded excessively costly equipment to recover it as latex, and further, only a portion of the rubber which was in the shrub could be recovered as latex. I think that in the future we probably would not be inclined to look on latex as a feasible means of extracting rubber from guayule because of the cost and because of the fact that you can't get it all out. About 40 to 50 percent of the rubber, perhaps, can be recovered as latex. In the research program that followed the expiration of World War II, I might just for historical sake note two things. First of all, as far as the Jordan in guayule milling, I think that was originally suggested by a Professor Waterman at the University of Southern California, and the suggestion was made to Dr. Robert Emerson who was working with a group of Japanese people at the War Relocation Center at Manzanar. He had developed a method of getting out small amounts of guayule using a Waring blender or something of that sort, and he was looking for means of expanding this and getting a bigger scale of production. I believe it was Dr. Waterman who had suggested the use of the Jordan. In our program following World War II, starting about 1947 and running until 1953, we were plagued with a great many demands which were not strictly research demands. Those of you who have been here before know that we produced quite a large amount of very carefully deresinated high-quality guayule crude for submission to various and sundry rubber companies and other testing agencies for comparative evaluation with synthetic rubber and *Hevea*. During that period of time we actually did our research by fits and starts. Ralph Chubb, who was greatly interested in this

business of deresination, and I have felt for a long time that in order to get guayule rubber that was comparable in quality at least to Hevea, deresination would have to be the route that would be followed. Ralph Chubb carried out a great deal of research on this. Unfortunately, shortly after the conclusion of the project in 1953, Ralph contracted cancer and died.

DERESINATION OF GUAYULE RUBBER

Eleanor C. Taylor
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The uses of guayule rubber have been limited principally by its resin content which ranges in conventionally milled rubber from 20 to 25%. The resins affect adversely the stress-strain characteristics and they change the compounding behavior. In addition, they apparently contain a factor that acts to facilitate oxygen absorption and speeds the aging of guayule crude. Since guayule does not contain a natural antioxidant as does Hevea, the crude rubber tends to break down and become tacky during storage unless protected by addition of an antioxidant. Removal of the resins delays this breakdown and improves the physical characteristics of the rubber vulcanizate.

Arguments for deresination are compelling. The quality of the rubber for most purposes is vastly improved and the resin recovered, in itself, may have a profitable market. The major argument against deresination is the cost for equipment and operation of the deresination steps in the process. A market for the resins recovered and a premium price for the higher quality rubber may, however, offset these costs. The decision to incorporate the deresination step in the process must depend on economic factors--the price received for the rubber, the cost of deresination, the use for which the rubber will be prepared and the market for the resins.

The notion of deresinating guayule rubber is not new. As early as 1903 Lawrence patented two different methods for deresinating the crude rubber, and Chute and Randel received a patent in 1910 on a process that involved deresination of the shrub before milling. Over the years numerous attempts were made in connection with commercial production of guayule rubber to produce a deresinated product but they were all abandoned because they were not economical under conditions then existing.

With the renewed interest in guayule during World War II, efforts to secure an adequate method of deresination were revived. The Intercontinental Rubber Company of Mexico filed an application for a patent on what was called the Boucher-Haden process. This process included washing the wet rubber particles from the mills--called "worms"--in 98% ethanol containing 2% sodium hydroxide at a temperature just below boiling. After extraction, the rubber was washed with hot water, with or without acid, to remove the alkali. A large part of the resin was removed and the insoluble content was reduced. Vulcanizates from the treated rubber were superior to those from the usual resinous rubber but shelf-aging of the crude was below expectations. A commercial installation for this process was made at the plant of the Intercontinental Rubber Company at Torreon, Coahuila, Mexico, where some deresinated rubber was prepared and marketed, but the method was not incorporated as a permanent part of the mill process. Presumably this was due in part to the poor shelf-aging of the crude, which has been attributed to residual caustic in the rubber.

During this same period, the Mare Island Navy Yard was experimenting with deresination of dried guayule rubber. Essentially the process consisted of acetone extraction of dried rubber which had been rolled out into a thin sheet. The solvent extraction was not too effective because the surface of the sheeted rubber exposed to the solvent was less than the surfaces accessible by other techniques. The process was similar to that used by the Diamond Rubber Company in 1910.

Hauser and leBeau deresinated commercial guayule rubber containing 26% resin by means of various solvents. They found that furfural was superior to acetone,

methanol or ethanol in that it was faster in its action and extracted a larger amount of resin. The process, however, has to be conducted at an elevated temperature.

Goodyear Tire and Rubber Company is reported to have investigated the treatment of dry, crude guayule rubber with aqueous caustic under pressure, alone or in combination with acetone. Little is known about the process but tires made from the rubber gave fair mileage.

Other techniques have been tried, many involving the use of caustic in one way or another. When caustic has been used, the rubber has usually broken down in storage more rapidly than products treated with other solvents.

The Emergency Rubber Project (ERP), in existence just 3-1/2 years--from 1942 to 1946--was under the pressure of wartime to concentrate on the most urgent problems related to rapid expansion of rubber production. That left little time to explore refinements leading to better rubber quality when quantity was the first objective.

During the last few weeks of active ERP operation a series of studies was conducted to find a chemical method to coagulate latex in the shrub prior to milling. The fresh shrub was parboiled, defoliated, cut and crushed, and then leached with water-miscible solvents. The latex was coagulated immediately and completely and the major portion of the resinous material removed. On milling, an excellent crude rubber was produced. Because of limited time, only two solvents were used--alcohol and acetone. Acetone was far more effective in reducing resins. Since recovery of solvent was high, the process was thought to have commercial use. The end of the wartime project precluded further study.

A method of deresination that received considerable attention by the ERP project was a procedure called "retting," so called because the action is somewhat like that which occurs in the retting of flax. Spence had taken out a patent in 1933 on this process which involves the reduction of resin in the shrub by inducing microbial action. A chance success in shrub retting revived interest in this procedure. In a study of storage of cut shrub as ensilage, some shrub with a moisture content too low for ensilage was placed in modified pit silos where retting occurred and a rubber of superior quality was produced.

In studies that followed it was learned that holding large masses of cut shrub quiescent in bins or tanks was not satisfactory regardless of the means of aeration, although small-scale batches worked well. Shrub placed in shallow piles on a floor and turned over from time to time by hand was successful but would have been too costly on a commercial scale. Shrub loaded in slowly revolving drums allowed for better and continuous agitation and, in addition, provided an opportunity for temperature control. Adequate control was obtained in small-scale drum rets but control over large-scale drums was never undertaken because estimated costs seemed excessive.

Eventually it was found that fairly successful large-scale rets could be carried out if the shrub were dug, baled and brought in from the field without delay. The bales were then parboiled, defoliated, rebaled and then placed in storage to ret, without temperature or humidity control, for 30 days. This technique worked well in the Salinas Valley with its moderate temperature and high humidity but it is doubtful that it would work as well in other climates. In addition, this type of "bale retting" involves the action of a mixed population of aerobic bacteria and fungi, and quite conceivably undesirable as well as desirable microflora might be present.

The biochemistry of retting was studied to a limited extent. Pure-culture rets were carried out with bacteria and fungi isolated from natural rets to determine the relative effectiveness of the various organisms. Fungi were active over a wider range of temperature and moisture conditions than were bacteria and were equally effective in reducing resin. Pure-culture rets were compared with natural rets of mixed microflora with virtually the same results on the shrub and crude rubber. Again, the economic factors arise: Pure-culture rets would require costly installation for sterilizing the raw material, maintaining pure-culture inoculum and maintaining proper environmental conditions during the ret.

The solvent deresination of guayule shrub or rubber has little effect on the physical qualities of the rubber until virtually all of the resin is removed. Retting, however, results in a physical improvement in the crude with a removal of 50% or less of the resin. This may be due to the exact fraction of the acetone-soluble material removed by the microorganisms or it may be due to a change in some other component associated with the rubber. Further investigations into this phenomenon may be rewarding.

This is about where matters stood when the wartime project was liquidated. When the research program on methods of extraction and processing resumed in 1947, the Bureau of Agricultural and Industrial Chemistry undertook quite detailed studies of deresination of both the shrub and the crude rubber.

Resins in guayule occur in resin ducts distributed throughout the plant and amount to about 5% to 15% of the dry weight of the plant material. The resin content varies with variety and age of shrub, season of the harvest, pretreatment of shrub and other factors. During the pebble-milling process, part of the resin becomes incorporated with the crude rubber as a major impurity. In most cases the crude rubber contains about one-half of the resin originally present in the shrub.

Rubber obtained by processing underesinated shrub contains approximately 20% to 25% resin. In general, the higher the resin content, the poorer the physical properties of both the crude and vulcanized rubbers. Great improvement in quality and uniformity can be obtained by eliminating most of the resin ordinarily present in guayule rubber.

Resin in shrub or rubber is usually determined by exhaustive acetone or alcohol extraction. Somewhat different values for resin content are obtained, depending upon the choice of solvent. The shrub contains more ethanol-soluble than acetone-soluble material, but the corresponding rubbers have either about the same or slightly lower values for ethanol solubles. These observations are not surprising since the resin is known to comprise a mixture of many different chemical compounds.

Preliminary tests with both solvents showed a more rapid extraction with acetone at room temperature, so it was chosen for subsequent work. Solvents such as furfural requiring elevated temperatures were not investigated.

The first studies of shrub deresination were carried out with shrub static in cells and the miscella flowing countercurrent to the cells. The apparatus used consisted of a series of 25 two-quart jars, each provided with a tube leading to the bottom of the jar and an outlet and air vent at the top. They were set up in sequence with each outlet connected to the inlet of the succeeding jar.

For these experiments, freshly harvested shrub was parboiled 20 minutes and defoliated. It was coarsely cut first through an ensilage cutter, next by rotary

knife cutter with an 0.5-inch screen, then crushed by passing twice through crushing rolls with a 0.002-inch clearance between rolls, and finally hammer-milled through a 0.5-inch screen. To avoid deterioration of the rubber, this preparation was completed on the day the shrub was harvested, and solvent extraction was begun the following day.

Each jar was loaded with 250 grams of shrub and acetone was introduced into the first jar with air vents open on all jars. As each succeeding jar filled, its air vent was closed. When all jars were filled the first jar was drained through the system forcing miscella from the last jar in the series. A gram and a half of acetone per gram of shrub was passed through the second jar and it also was drained. This procedure was continued with each succeeding jar in the series until the last jar was drained. The miscella flowing from the last jar was cut into successive two-quart fractions, and each fraction was then used in order of emission in succeeding runs.

The acetone remaining on the shrub was recovered by back-washing with water in a similar manner starting with the last jar in the series. Four grams of water per gram of shrub was added at each jar for the draining procedure. This leaching miscella was also cut into fractions for use on the next run.

When the miscella had been used on six successive runs, it was considered that equilibrium conditions had been established, and each two-quart jar of miscella was sampled for analysis of acetone, resin and water solubles content.

The different stages of extraction are divided into 100 theoretical stages for convenience and ease of presentation. Stages 1 to 66 cover the dehydration of the shrub and extraction of the resins by acetone; 67 to 100 cover the leaching of the shrub with water to recover the acetone.

The rapid increase in acetone concentration in the miscella shows that the acetone dehydrates the shrub rapidly and completely, coagulating the latex. Thus air-drying is avoided, which has a deleterious effect on the rubber.

In the back-washing phase, the miscella again changes very quickly from nearly pure acetone to a low acetone concentration, and there is no acetone going out of the system with the miscella on the deresinated shrub.

Of extreme interest is the appearance of two high points in resin concentration in the miscella, one at 60 to 65% acetone and the other at 85 to 90% acetone, denoting a partial fractionation of the extracted resins with respect to solubility in the advancing miscella.

At an early stage in the system, when the shrub was losing its natural water content, a high concentration of saponin-like materials was observed. In later studies the shrub was leached with hot water prior to acetone extraction to prevent formation of precipitates that appeared in the system at the point where the miscella was changing from a high acetone content to a high water content.

The ratio of miscella to shrub on a dry weight basis was 12 to 1, and good extraction was obtained in about two hours. Limitations of the equipment prevented investigation of shorter extraction times and different miscella to shrub ratios.

Analyses of the treated shrub and the rubber milled from it showed that resin content of the shrub had been reduced from 7% to 2% of the dry shrub weight. The

rubber from the deresinated shrub contained 2% resin, whereas the rubber from the underesinated shrub contained 22%.

In order to prepare sufficient quantities of rubber for physical testing and to make further observations on the process, tests on a semi-pilot plant scale were conducted. A battery of eight tubes, 10 feet long by five inches in diameter, were mounted vertically in series. Each tube contained five kilograms dry weight of shrub. The procedure was essentially the same as followed in the small-batch tests.

After equilibrium conditions were approached, 2-1/2 gallons of miscella were removed from the cut where the resin concentration was 4 to 5%. This removal was done to maintain the resin balance in the system. The acetone concentration in this miscella was 60 to 75%, equivalent to 1-1/4 pounds of acetone per pound of shrub, giving some indication of the amount of acetone that would have to be removed from the resin. However, the concentrations of resin in the miscella and the amounts of acetone to be removed and added are not necessarily the optimum that could be achieved in a continuous closed system.

The acetone can be completely recovered. In distillation tests on water, acetone and resin mixtures, there was no plugging by resin, and the separation of water and acetone was normal, indicating no interference by any of the dissolved materials.

The average recovery of rubber hydrocarbon from 29 millings was 90.4%, which is comparable to recoveries obtained from resinous shrub. The extraction process removed 65 to 70% of the resins in the shrub and resulted in a reduction of more than 90% of the resin normally present in the crude.

In Table 1 physical tests of the deresinated rubber are compared with resinous rubber and with Hevea No. 1 Smoked Sheet. The stress-strain values show that the deresinated rubber is distinctly superior to the resinous rubber and it approaches Hevea in quality.

Table 1. Physical Tests

	MOONEY VISCOSITY	TENSILE p.s.i.	STRESS AT 500% ELONG.	ULT. ELONG. %	SHORE HARDNESS
RESINOUS GUAYULE	50	2600	350	820	26
DERESINATED GUAYULE	95	4060	830	770	40
HEVEA NO. 1 SS	96	4620	865	790	41

Rubber produced by the pebble-milling process is in the form of loosely aggregated, porous, spongy particles about 2 to 3 mm. long by 1/2 to 1 mm. in diameter. The form of these "worms" makes them readily adaptable for the removal of resins so long as they retain their spongy character.

Preliminary experiments on worm deresination using excess volumes of chemically pure acetone showed that with solvent at 20° C the resin content dropped 76% in two minutes exposure and after three minutes 81% of the resin had been removed. With

solvent at 56° C, the two-minute exposure resulted in 89% reduction and three minutes gave 95% reduction.

The next stage of research was designed to determine the number of stages required and equilibrium conditions in a countercurrent procedure. At a solvent-to-rubber ratio of 2-1/2 to 1 in each stage, deresination was obtained in 20 stages while maintaining equilibrium at a peak resin concentration of 10% in the miscella at the seventh stage.

In 1951, 4,000 pounds of deresinated guayule rubber were requested for truck tire road testing. To produce it, apparatus modeled on the laboratory set-up was used. It consisted of a 35-gallon stock pot with a drain at the bottom, a stainless steel 80-mesh screen basket fitting inside to hold the rubber, and an air-driven mixer to stir the rubber during treatment.

The number of stages was reduced to 16 and peak resin content was kept at 6%. The miscella from each stage was saved and reused on subsequent batches of rubber except for that from stages 1, 2 and 6. Miscella from stage 1 was withdrawn to remove the major portion of the water from the system. This brought the peak resin concentration into stage 6. Attempts to dewater the rubber by pressing it before treatment were unsuccessful because the rubber clumped, which resulted in lumps of deresinated rubber.

An antioxidant was added in the last stage, and the rubber worms were dried for two hours in a circulating air oven at 40° C. The average residual resin content in the rubber was 1.9%.

In 1952 an apparatus was built in which all factors affecting deresination could be controlled. It consisted of a container 18 inches x 20 inches x 4 inches deep with a screened bottom and a spray overhead. This container fitted into a vapor-tight housing arranged so that it drained completely into the suction side of a pump which circulated the miscella through the spray head. A heat exchanger in the circulating line controlled the temperature of the miscella.

This apparatus could be considered as one stage or section of a moving belt extractor. In operation, however, the bed was static and the miscella circulated by the pump was moved countercurrently by introducing the various cuts of miscella in the proper order.

A standard procedure was developed: 1) The rubber worms were skimmed directly onto the screen from the scrub mill flotation tank. If they had to be stored, they could be held under water for up to three or four days and then broken up with live steam. The worms were spread uniformly and without packing about two inches deep on the screen. 2) Twenty-five cuts of miscella were used. Miscella was removed from both cut No. 1 and a later cut where the acetone concentration was about 90%. The amount of miscella removed was calculated to be just sufficient to remove the water and resin coming into the system with the rubber. 3) Fresh acetone was added to maintain the 25 cuts at a miscella-to-rubber ratio of about eight to one. 4) Each cut of miscella was circulated through the rubber for two minutes and allowed to drain two minutes. 5) The rubber was dried in a circulating air drier at room temperature.

No trouble was experienced with the loss of fine rubber through the screened bottom of the container. As the miscella circulated, any fines which did pass through were filtered from the miscella by the bed of rubber itself.

The rate of percolation of the miscella varied widely from run to run, possibly because of the size of the worms, the density of the bed or other causes. In each case, however, it was slowest at the point of highest resin concentration.

In some runs acetone containing 2-1/2 to 3-1/2% water was used, and deresination was successfully accomplished. This is of great practical importance--the fact that pure acetone need not be used.

Studies were made at various times during an entire year; two different strains of guayule shrub were used (593 and 4265) and two different age groups (four years and eight years). The crude rubbers handled ranged in resin values from 20% to 35%. Deresination proceeded normally in all cases.

When it became necessary to produce some 6,000 pounds of deresinated rubber for further tests by private companies and in airplane tires, an even larger deresinator was built, modeled on the apparatus just described.

Fluctuations of ± 20% in the quantity of rubber handled in a deresination run (nominally 25-pound batches), variations in the worm size, tendency of the rubber to pack at different times, holding time of the wet rubber worms up to 70 hours before deresinating--all these factors exerted only slight effects on the system and in the production of a high-quality uniform deresinated rubber. The average residual resin content of 244 batches was 2.1 ± 0.3%.

While deresination studies were under way, a thorough search of the literature and patents revealed that no solvent extractor in general use was suitable for deresination of guayule, either as shrub or as rubber. A continuous belt type of extractor for oleaginous substances might be adapted, however. Designs were drawn for a continuous belt extractor where proper countercurrent extraction conditions could be maintained on a moving perforated belt subjected to flooding percolation from a system of pumps, pumping from a series of tanks beneath the belt to sprays above it. For a variety of reasons, primarily the demise of the project, this device was never built. A detailed description of it appears in the Final Report of the Natural Rubber Extraction and Processing Investigations.

Whether to deresinate the shrub or the rubber depends on several factors. The advantages of shrub deresination are: 1) the recovery of more resin, amounting to perhaps 1/2 pound per pound of rubber; 2) the possible recovery of resin fractions not found in the rubber worms; and 3) the recovery of water solubles that amount to as much as 15% of the shrub weight. The principal argument for worm deresination is that a much smaller volume of material need be handled through the deresination step, allowing for smaller-scale equipment. The relative amounts of solvent needed should not be a critical factor because essentially all of it can be recovered and recycled.

The market for the resins may well play a vital role in determining the economic value of deresination. The quantity and composition of the resin complex vary, depending on whether it is recovered from the shrub or from the rubber worms.

Shrub resin is essentially a total extractive. The most interesting fraction is a shellac-like gum resin which can be easily polymerized to a heat-resistant, clear coating of good solvent resistance. It is this fraction, constituting about 35 to 50% of the shrub resin, but a much smaller proportion of worm resin, which undoubtedly has been the portion of guayule resin of prime interest to varnish and paint manufacturers.

The worm resin is not a total extractive but comprises chiefly the nonpolar constituents. The more polar gum resins remain with the bagasse by virtue of a greater affinity for wood rather than for rubber. More than 37% of the worm resin consists of unsaturated long-chain fatty acids, notably linoleic acid, along with traces of linolenic and oleic acids. Linoleic acid has long enjoyed an established position in the paint and varnish industry.

The terpenes of guayule constitute a potentially valuable "naval stores" type of by-product. Volatile terpenes, which comprise about 3 to 5% of the worm resin, include alpha-pinene, dipentene, cadinene, partheniol and others. Sesqui-, di-, and higher terpenes are also readily obtainable in significant quantities from the nonvolatile unsaponifiable fraction.

Cinnamic acid, present in resin as the ester of partheniol, from which it may be obtained by saponification, is also a by-product of established value in the cosmetics and pharmaceutical cosmetics and pharmaceuticals industries.

Another constituent of guayule found in the deresination miscella is betaine. Commonly obtained as a by-product of the sugar beet industry, betaine has a limited market as a pharmaceutical and as an intermediate in the production of surface-active agents, disinfectants and other chemicals.

The cuticle wax from guayule, which constitutes about 0.25% of the fresh weight of the foliage, is one of the most promising by-products of the guayule processing operation. Its relative hardness, molecular weight and melting point justify its consideration as a substitute or extender for carnauba wax. Further research on guayule resins could well prove most rewarding.

The ultimate test for a deresination process is, of course, the amount of improvement in guayule rubber that can be obtained by the treatment. The enlistment of industrial cooperation in guayule rubber quality evaluation was considered the best means to assess the improvement obtained through deresination. Sample lots of deresinated guayule rubber, totaling nearly 9,000 pounds, were distributed to various industrial organizations. The cooperating members included the major rubber manufacturers as well as smaller companies and comprised an excellent representation of the entire American rubber industry.

To summarize their results briefly: The guayule rubber had essentially the same molecular weight as Hevea and the infrared spectra were the same. The stress-strain properties of guayule rubber were nearly equal to those of Hevea if adjustments were made in the compound recipe. Deresination removes organic acids present in guayule rubber, so it is necessary to compensate for these acids which would normally activate the accelerators in the recipe. Slight changes in the recipe resulted in large changes in physical properties of the vulcanizates.

In numerous other physical tests and in analysis of dynamic properties, no marked consistent differences from Hevea were observed. Several tests, however, did indicate that guayule rubber may have a greater heat build-up.

Some observers found that the guayule rubber had a faster breakdown rate upon mastication which may be an advantage in certain applications. When guayule rubber was compounded in a tire tread recipe it extruded better than did Hevea Smoked Sheet. This is an important advantage in processibility.

One company used guayule rubber in the fabrication of electrician's or lineman's gloves which must be very durable and have high insulating qualities. Compared to the standard Hevea gloves, the guayule gloves showed extremely low leakage values.

Of special importance was the evaluation of deresinated guayule rubber in tires. For tests of heavy duty truck tires, Firestone Tire and Rubber Co. of Akron, Ohio, fabricated tires in size 9:00 x 20, 10-ply rating. They made three tires each from four different carcass compositions: 100% guayule rubber, a blend of 45 parts of guayule with 55 parts GR-S synthetic, a similar blend of Hevea with synthetic, and a 100% standard Hevea carcass. Treads in all cases were "cold" GR-S. Road tests were conducted by the Government Tire Test Fleet at San Antonio. Tire loads, with gravel ballast on the trucks, were 145% of the recommended maximum to increase the severity of the test.

The test, conducted during the summer and fall of 1951, showed that the 100% guayule and the 100% Hevea carcass constructions were equal in durability; one tire of each was still running at 50,900 miles when the test was discontinued. Based on average miles to failure of the other two tires of each type, the guayule tires stacked up a few more miles than did the Hevea. The blends with synthetic were definitely inferior to the 100% natural rubber constructions, but about equal to one another.

The tires were fitted with thermocouple wires to permit measurement of temperature, indicative of relative heat build-up. The tires containing synthetic blends had the highest running temperatures, while the 100% guayule and 100% Hevea were essentially the same. Tire treads on the 100% natural rubber carcasses were about equal in resistance to cracking.

Passenger car tires manufactured by Goodyear Tire and Rubber Co. were tested in 1952 following the same experimental plan. Any attempt to evaluate carcass durability would probably not be valid because most of the tires were worn to the fabric before the test was completed. An earlier test with just two passenger car tires rated the guayule tires at 82% of the Hevea for wear, and there was no difference in cut growth or tread cracking.

In summary we can say that properly handled deresinated guayule rubber is equivalent to Hevea for most uses, including truck and passenger car tires. The basic rubber molecule is there. Removal of the associated resins reveals the value of the rubber and the resins recovered may be a bonus.

The economic and political situation has changed so much since this research was done 25 years ago and so many technological advances have been made, many of which certainly can be applied to guayule processing. We need now to re-evaluate guayule as a profitable agricultural crop and a useful raw material for industry.

Discussion

Comment: (K. Taylor) Before I call for questions, I'd like to make two very brief comments. You will note that she referred to large amounts of rubber that were prepared for testing purposes by tire companies and other people. Those were done in relatively small batches, and since we had only a small crew of people we were often precluded from doing research we wanted very earnestly to get to. Joel Schechter, I think perhaps you might be interested in a possibility that occurred

to us many years ago. I think it was in 1950 when I hazarded the guess--and it still remains a guess and maybe a hazard--that the resins might become the product and rubber the by-product.

Question: (Irvin Feustel) I want to ask Ken: This bale of rubber over here, the 50-pound bale, was it one of the bales that was saved out from those large batches that were sent to the rubber company for tire manufacture?

Answer: (K. Taylor) Yes, it was from the last large batch we made.

Question: (Irvin Feustel) I'd like to ask Eleanor: The shrub deresinated rubber seemed to have a little higher tensile strength than some of the worm deresinated rubber. Is that just a matter of chance there? Do you think there is a difference perhaps in the quality of rubber?

Answer: (Eleanor Taylor) I have no way of telling because I don't recall that any direct comparisons were made between shrub deresinated and worm deresinated rubber. I don't think they were from the same batch of shrub. And of course there's so much difference in what recipe was used in compounding; you're going to get figures all over the map unless they are really controlled tests. So I wouldn't want to compare shrub deresinated with worm deresinated on the basis of quality at all.

Comment: (Irvin Feustel) No, I don't recall any results either, except the results in general that we had for worm resinated rubber seemed to be lower tensile strength than is in that table.

Comment: (Eleanor Taylor) You were using bigger batches of rubber and it may have stood around longer, too, more than the shrub deresinated did--it was processed rapidly after it was harvested from the field. There's also the possibility there was some deterioration during milling with the resin present in the system.

Comment: (Irvin Feustel) Perhaps this milling of fresh shrub and the deresination of the shrub might give less opportunity for deterioration than milling of field-cured or stored resinous shrub which allows the resin to stay with the rubber a little while, resulting in deterioration.

Comment: (Eleanor Taylor) The work was done by Jim Meeks on molecular weight of rubber. He found there was a decrease in molecular weight. As shown by Mooney, viscosity, no matter what you did to the shrub or the rubber, went no place but down. It just varied in the amount it decreased at each step as it went through the process. So the more rapidly it is processed, and you get an antioxidant on it, the better off you are because the rubber molecule apparently suffers as you go along in each step of processing.

Comment: (K. Taylor) I think that any comparison of the two would have to be carefully done and carried out on a sound, designed basis where the results could be analyzed statistically before we could determine for sure that the differences were due to some actual treatment or due to chance.

Question: (Les Baird) I wonder if you had seen the article that was published in Industrial Engineering Chemistry by Dr. Robert Emerson and associates of Cal Tech. In their particular studies they got as high as 5,000 p.s.i. tensile. Do you have any comments about that test? It is probably one of the highest that I've ever seen in the rubber literature.

Answer: (Eleanor Taylor) I don't know of any of the details about how they handled that. Perhaps someone else here does.

Comment: (J. Bonner) That is just a figment of how you compound the rubber. Compounding is black magic and you can get any tensile you want by altering your black magic.

Comment: (K. Taylor) I entirely concur with you, Dr. Bonner. You can do miraculous things with rubber if you add enough stuff to it. I think in fairness we should probably all stick, as we did in our tests, to the American Standard Testing Methods, so that our results are comparable one to another.

Comment: (Paul Allen) I'd just like to comment again on the effects of the resin. It is clear that there are some of the fractions which are more deleterious than others, and that part of the resin action is not just the dilution of rubber but an active deleterious effect. This showed up particularly well in some of the retted rubber which gave a considerable improvement in rubber quality with relatively little loss of the resin. Subsequently Dr.Haagen-Smit did some fractionation by fractional distillation. A test of these fractions showed that some of the fractions were deleterious but most of them were not.

Question: (Dwayne Chase) You mentioned very briefly wax and you talked about cuticle wax. I don't know much about cuticle wax and I also missed the percentage of the composition that the plant contains.

Answer: (K. Taylor) The cuticle wax is the waxy coating that forms the cuticle surface of the leaves. Most of the wax is found in the leaves; there's very little found in the shrub itself. It may be that in the very young growing tips of the shrub you will get a certain amount of the cuticle wax. As to the precise percentage that is present, I don't have that information.

Comment: (Eleanor Taylor) The only figure I found for it was one-quarter percent of fresh weight, whatever that means. I don't know how wet they were--that is, the leaves--one-quarter percent of the fresh weight of the leaves is wax. I understand that it is easy to recover. It's soluble in hot acetone; you cool it down and you have hard wax. No trouble in recovering; very white wax, very pretty wax.

Comment: The wax, I might add, is very comparable in many respects--in milling, in hardness, in gloss characteristics and what not--to carnauba wax. It is a whiter wax than carnauba.

RECENT RUBBER PRODUCTION ACTIVITIES IN MEXICO

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I would like to make some brief comments on the general panorama of the guayule produced in Mexico. At the present time the most significant development has been the escalation in the price of raw materials. This situation has been the catalyst in the formation of a new multi-detente between the developed and developing countries. The price escalation is mainly generated by an imbalance that has come about in the supply, and demand of raw material between them and rubber constitutes one of the most affected.

The gradual utilization of the renewable natural resources is actually one of the greatest priorities that countries like Mexico must assert, and in that order the best utilization of our lands acquire a relevance in the national development program. Guayule has been exploited politically since 1910 and principally during the Second War by huge companies. With the creation of the National Council of Science, Mexico is for the first time attacking in an organized way this problem and by means of representation of governmental agencies of the National Arid Lands Office and Research Institution at our center, fully integrated programs have been started since 1973. The purpose of this paper is to present the most relevant aspects of our program on guayule, trying to discuss the technical side but also to analyze the importance of the rural development of the Mexican arid lands. Since 1910 this rubber has been one of the main points of interest among the renewable resources of the Mexican desert. Definitely Mexico constitutes the natural habitat of this plant. Its ecology is the determinant in order to obtain the growing and the rubber content in a short term. In its native habitat it has more resistance to be attacked by insects, fungus, etc. Much experience has been gained in terms of cultivation and accommodation to different regions. Numerous processing plants in the Mexican territory were established but unfortunately there are no available data on the exact amount of rubber produced and exported. The Mexican participation was restricted mainly to the harvesting labors, transportation and very limited to the industrial processes. For that reason, our experience was restricted to the farmers or the peasants and from the technical point of view we could not penetrate into the technology and so we were unable to continue the utilization of these resources. Of course, we were just emerging into the world of modern technology. With a lot of training, human resources, and the absence of any intrastructure in scientific research and technological development. For our country the guayule is a legend of temporary prosperity among the Mexican peasants of arid lands.

Fifty percent of Mexico is covered by semiarid and desert lands, traditionally representing a major problem in the national development. With the scarce natural resources, some of them like candelilla and natural fibers are permanently exploited, but have profound problems arising from the restricted market and the replacement by synthetics. The economic chemical industry started in 1950 polarized the economic situation by creating important industrial areas with which many of the growing populations of the arid lands were integrated. With the development of the national petro-chemical industry, started in 1965, the production of synthetic rubber with foreign technology reached a gross amount of 60,000 pounds in 1974.

The national rubber market is growing for vital reasons, not only the demographical situation but also the increasing population of the automobile. In terms of natural rubber, the national consumption gave a figure for 1974 of 35,000 pounds representing a 90% importation from Southeast Asia. The forecasting for 1980 predicts an amount of 55,000 tons. In 1960 the Mexican government started an ambitious program to grow Hevea plantations. However, this program failed to reach its objective principally for the lack of technological programs involving not only industrialization and improvement of the quality, but also economic aspects. This panorama is not very pleasing in terms of the work crises related with the general scarcity of raw materials, and our great dependence on importation of natural rubber requires a plan to take advantage of our natural resources and use them as an important source to attain self-sufficiency. The implementation of a program of this nature has to consider many factors, not only the socioeconomic and marketing factors, but also to create the necessary intrastructure in order to develop a well-designed program and effective government policies. In that sense the use of our natural resources demands a joint program including on one side the research institutions, the governmental agencies dealing with the planning of science and technology, and also the responses of rural development.

In 1971 the National Council of Science and Technology was started--the first organization devoted to establish the national policies to find the best alternatives to use them in terms of national needs. At the same time the National Arid Lands Office was founded--the first attempt to attack the problems of the desert in an organized way. These two organizations started a program oriented at the beginning to find uses for the natural resources. The most important--the guayule project--was started in an exploratory way in 1973. However, the task was difficult to accomplish mainly for the lack of elements to carry out the research activities, principally those of applied nature. The National Council of Science and Technology started to create similar research institutes located in strategic regions which was an important factor in the development by means of research programs oriented to the regional resources. Following these objectives the Research Center in Applied Chemistry was established in Saltillo. The beginning guayule was selected in one of the main lines of its activities. A joint program was in general trying to generate the information at all the necessary levels required to find the best alternatives to arrive at aid for industrialization based on the modern scientific and technological knowledge.

The implementation of a research and development program requires the establishment of a complicated network of specific activities at different levels. In order to generate not only basic information, but also to carry out applied experiments and experimental developments, specifically in the guayule group and guayule rubber, it seems that the basic research is a wasteful exercise and there are some reports dealing with this topic. But we have to take into account that almost all experiments in the past were made by means of older techniques and at this moment we can include new methods in order to obtain an overall picture of all the basic aspects concerning the rubber characteristics.

The network established that I am going to discuss contemplates some of the most important aspects of the basic points of view and also the general state followed to the configuration of industrial process. Of course, the experience and the tremendous amount of work done was the main source of information. Into the basic level, in order to obtain a complete physical chemical characterization and physical-biological characterization of guayule rubber, the topic discussed below has been covered in the past.

Some attempts were made in the past like infrared spectroscopy and molecular weight determinations but the development of the rubber industry brought many more techniques in order to insight more deeply into the basic aspects of guayule rubber. In terms of microstructure, Stadley and many other people using infrared spectroscopy found a 97.8% of cis-1-4 structure and the rest of 3-4 units. These results were compared by this kind of spectroscopy. However, there are many arguments around the exact cis-1-4 structure. We were using nuclear NMR in 300 megahertz resin by this technique available since three years ago. There are many reports dealing with the 100% cis-1-4 structure in Hevea proven. The results show that from the microstructure the Hevea and guayule have the same microstructure but the difference is that no 3-4 units could be found in guayule.

In terms of chain dimensions or molecular weight many of the resources that we find in the latter were very confused. Almost all of them present a result showing that the guayule rubber has a lower molecular weight than the Hevea rubber. Perhaps the problems related with the handling of the material, the hard problems that represent the utilization of rubber into the solution may affect these kind of measurements. By using chromatography as a means of the size separation of the molecules, we have been working on all the problems related with the molecular weight of guayule rubber. As we can see in this picture,* the molecular weight decreases from your left to right. Guayule and Hevea were obtained from fresh latex and we have to take out the jell content. Guayule was obtained entirely from shrubs within two or three days of harvest. As we can see, the solid parts of the rubber in the guayule and Hevea shows almost the same molecular weight and approximately the same molecular weight distribution. Regularly we have been obtaining molecular weights higher in guayule than in Hevea. With this kind of technique we are able to follow not only the degradation during the storage that was mentioned in previous talks, but also the effects of the processing conditions and the effects the amount of resin present in the rubber.

This is a typical molecular weight distribution of guayule rubber.* By the same technique we can separate the family of compounds by the molecular size. We believe that in some sense they are the same as presented in the talk by Stadley. Of course, each one of these peaks, if we make a saponification this peak disappears. That means there are the triglycerides present in the resin. At this peak, the lower molecular weight peak by gas chromatography presents a tremendous amount of components. It is hard to resolve these resins. Besides, with the information we can at the same time measure the aggregate content and also the kind of resin. By light scattering, measuring the average molecular weight and the refractive index and all the parameters involved in chemical characterizations we made several runs. We have been working on this topic. For instance, we have guayule--the average molecular weight for $2.5\text{-}10^6$ and from Hevea rubber we have 2.02. In the polydispersity of the rubber we always have been finding a lower polydispersity in guayule rubber than in Hevea rubber. This 2.4 is variable but generally we are getting polydispersity between 2.1 - 2.3 in guayule rubber. This is a very important figure in terms of the processibility of the rubber.

Other points of interest that were also mentioned before is the jell and the branching content of the rubber. The jell, as you know, is a three-dimensional structure, insoluble matter that usually represents a problem during the milling. We have been finding by several techniques that the jell present in the guayule rubber before the processing exceeds 3-4% of jell. This is a very important feature of the guayule rubber. The Hevea rubber also presents high amounts of jell.

*Slides

Related with branching, that is also a very important characteristic of the rubber. We have been actively working in determining the degree of branching in the guayule rubber by several techniques like light scattering, concentric viscosities and chromatography. We have been finding that guayule rubber presents a highly linear structure; very low branching content is present. We are just starting this kind of aspect and we expect to finish it at the middle of 1976.

There are no data at the present time relating with the glass transition, heat capacities, thermal instability, thermal oxidation stability and the inference of resins and antioxidants in this behavior. At the present time we are working to establish similarities between Hevea rubber and guayule rubber into the term indicator. Transition is exactly the same minus 75° C. Heat capacities, as I will show you later, are the same order. Thermal instability to resist thermal oxidation in natural Hevea rubber and natural guayule rubber present the same activation energy by differential calorimetry. All these aspects are on using calorimetric techniques to alleviate the thermal instability.

We are also starting some rheological work dealing with the properties of resinated and unresinated rubber. From the applied label, of course, there are two main sources of information. The resource that we have been talking about in the last papers--the resource obtained in the former guayule emergency program, especially reusable in milling and deresination. The advances in process derived from this synthetic rubber elastomer industry, mainly the modern drying systems and new techniques to recover rubbers from hydrocarbon solutions simultaneously, and now the resination systems that we are also emulating at the laboratory scale. Many of the most relevant activities I am going to present are just simple revisions of experiments reported previously.

I think many of the main aspects dealing with resin have been covered. However, we are starting a program now to evaluate the different several alternatives to use the resin. We strongly believe that the resin represents the main product and the rubber the by-product. We have several programs going on that way and we are about to have some evidence of the possible views of possible uses of resin, the economical point of view that will represent the very important factor in the process. Around 20 to 30% of total dry weight of the rubber is cellulose. By means of other research institutions in Mexico the cellulose has been evaluated in order to find uses and they are very promising. In terms of antioxidant evaluations we have been covering by the basic point of view by the calorimetric techniques and all those techniques that we are also starting to work measurements on the rubber and also by ASDM procedures. I think one of the most important problems in the guayule rubber is the stabilization. Of course, during the second war many of the natives used to incorporate the antioxidant into the rubber. We think now that the availability of industrial equipment and the incorporation of antioxidants as well as many other ingredients into the rubber will make it easier to do.

Some papers mentioned that the cork in guayule represents a problem in the industrialization process, and it has to be eliminated through several steps. Some correlations were established with the normal cork obtained from cork trees, for instance, the density of cork trees is .2 to .3, the specific gravity for guayule cork range between .3 to .6 which is very much denser than cork trees. From the thermal behavior the guayule cork and the tree cork are very similar excepting in high temperatures from 350° and 400° C. All the results were obtained by calorimetric techniques. From the large-scale experiments we have been repeating many of the topics discussed before--milling, caustic treatment, good resination, the solving coagulation, drying, etc.

There are many of these aspects that cannot be carried out in the proper way at laboratory scale. It has to be done in the proper equipment. In that order from the milling the large scale was also reviewed the general information available and also to establish several alternatives to define a flow sheet. From the milling and concentration I strongly believe that the milling and the concentration of material has to be done. The solvent consumption in order to extract resin by solution is very hard to accomplish. From the economical point of view we strongly believe that it is very hard to get nice figures. For that reason we have been working on the milling and concentration and of course we have been evaluating several milling systems.

I would like to present some results from the pilot plant facilities that we are getting in Saltillo. From the resination point of view, the rubber obtained in the previous steps range between 17% and 25%. The deresination of guayule that we are working actively is the deresination by solar destruction. The acetone extraction, I strongly believe, at this moment is the best alternative way to do it. Of course there are several methods to carry out work in a fixed bed or fluid bed. The percolation presents many difficulties in order to carry out. The permeability, the channels established through the bed, and all these factors reduce tremendously the efficiency of the process. We strongly believed that the deresination had to be carried out in a fluid bed.

The elimination of cork and the rest of the fibers is hard to accomplish, even with the pressure system. There still remains about two to three percent of insoluble matter. The high quality rubber is very hard to obtain. In the system we were simulating there still remains small amounts of insoluble matter. We hope that it is possible to obtain a very pure rubber completely clean of insoluble matter by dissolving and coagulating. This is a technique actually used in the synthetic rubber industry. The solution---------in polyisoprene or polybutadiene highly specific is carried out in hexane or cyclohexane solutions. We have been working on the solution and the coagulation------meaning the recovery of the rubber from the hydrocarbon solution. We have at this moment several facilities to carry out this step. This also presents the prospectives to obtain a very homogeneous rubber and very well distributed the antioxidant in it. We are working on the solution and the solvent coagulation. The aspect of the drying mentioned before represents a very complicated step to carry out in rubber. Even in vacuum I strongly believe that the guayule rubber had a considerable amount of moisture remaining. That moisture affects tremendously the processing and the compounding of the product, because you never know what amount of water you are sending with the rubber.

You have to change the compounding; you have to change many things in order to obtain the same properties and at laboratory level it is very hard to simulate the drying of the rubber. At the present time there are several alternatives to carry out the drying. We have been working with the mechanical drying of the rubber--that means by mechanical drying, two steps: first, taking out the 80-90% of the water by mechanical means, and after that we are also working with the mechanical by the same kind of experiment. The result obtained was the efficiency that we are getting in the first place; that means milling and concentration are very important. We are getting figures between 90 and 95% of the rubber content.

I would like to mention that in Mexico the four most important regions, Zacatecas, Durango, Cohuilla and Torreon, that the most important are Zacatecas and Durango from the inventory aspect. In that order Zacatecas and Durango present the higher rubber content, contents between 16% of rubber in Zacatecas and about

14% of rubber in Durango. However, the molecular weight in that of Cohuilla is in the positive direction. We are getting more rubber, but at the same time we are getting in some ways lower molecular weight. The roots on the plants present different molecular weights. The rubber from the roots is higher in molecular weight than the rest of the plant and for that reason is very hard to standardize. These characterizations depend strongly on where you get your guayule. In that sense we have been working in this project and I am going to present some slides showing the facilities that we are getting right now in order to establish the finest configuration of a process. We also believe that we are in shape to start to work in a small pilot plant--a small demonstration unit--to start to get experience with the new industrial assistance and the next plants we can innovate from the technological point of view some of the steps.

We have split the process into two main blocks. The milling and the concentration has to be done in that order. We were measuring different milling systems choosing hammers, several steps in the hammers, flotation, calcite treatment, conditioning in the rubber, and all this. We obtained the finer of the concentration step and the conditioning of rubber with around 2-3% of the soluble matter. The worms, as mentioned in many papers, are small--one millimeter in diameter, and very easy to deresinate. As soon as we get the material floated we can start to deresinate the solvent and coagulate. We have three alternatives: go to drying, and to obtain a resinous rubber, or dissolve or coagulate the resinate. We were also working in the dissolving step to coagulate in a nonsolvent like acetone, or isopropanol, or nonsolvents for the rubber, but solvents for the resin. With this system there are many problems involved. First we are mixing solvents; we have around three solvents, water by one side, the nonsolvent and the solvent. In order to carry out the continuous process it is very hard to obtain in a batch. It presents many difficulties because the resin content is going up accordingly as we are coagulating the rubber. Also from molecular weight, low molecular weight is remaining in solution. We think that the best alternative is to deresinate. The deresination that we are working on is by acetone. All the previous works are very valuable and all the results are mentioned by Mr. Stadley. We repeat all the experiments and we get almost all the same results. For the mechanical drying, we have many alternatives to obtain constant viscosity rubber or to increase the rubber or to increase the viscosity by the new method used in Hevea. There are many alternatives to bleaching the rubber. I am going to present some slides of the demonstration unit that we have starting to work in Saltillo.

This program was supported by the National Arid Lands and National Science Council and the National Council of Science and Technology. We installed a private plant in Saltillo, starting the construction four months ago. We are using in the experiments several hammer mills in order to reduce the sizes. We have also some caustic treatment to incorporate some chemical energy into the guayule rubber in order to make easier the deresination process.

These are some suggestions in order to carry out the caustic treatment. We are working with some kind of chosen refiner for the fiber. It was mentioned before that you have to set all the conditions and all the same part of the receipt of material, the start of flotation time, women to make the warfs and reduce the size in the warfs. This is the part for accomplishing of the rubber to reduce the particle size. From this we are going to deresinate; unfortunately I couldn't get slides of the finished system we are making in a fluid bed. The unit of coagulation is almost finished. With this unit we can make all kinds of chemical modification in the rubber. The coagulation is in water. Some tanks were constructed to

keep the rubber before drying. The drying units that we were using were bought in the U.S. Part of the drying unit in the top is the mechanical expeller. We are introducing the rubber with 50% of water and in the first step the water is reduced to 10-15%. The expeller in the top and in the bottom is the expander. This is just like the same system to take out the oil from the seeds by mechanical treatment. This part belongs to the expander, which is the drying unit. You are taking the 15% of the water out by means of mechanical energy. You are changing the mechanical energy and thermal energy and pressure. You have to get 15% and then when the rubber comes through the dye, the very small dyes, the change in pressure flush the remaining water. This is the drying unit, the cooling toner for the system when the plant was started.

We are starting to configurate the process or several alternatives in the process that we hope to work on in 1976 in order to define the best alternatives. But I think we have chances to make many chemical modifications to the drying step; there are possibilities to introduce in more homogeneous form the anti-oxidants, or the bleaching agents, or many other components. That is the general view of the program.

PHYSIOLOGY AND CHEMISTRY OF GUAYULE

James Bonner
California Institute of Technology

By the winter of 1939 it didn't take any seer to understand that there would be interruptions in the supply of essential foreign imports to the States. The only remaining question was what could a plant physiologist contribute to the requirements, things that the U.S. requires that would have to be imported and that we normally import. The obvious import to which a plant physiologist could perhaps contribute was our importation of rubber. In 1939 and prior to that time we were almost totally dependent upon rubber imported from Southeast Asia. So in the latter part of 1939 my colleague, F.W. Went, and I made an appointment with the president of the Intercontinental Rubber Company, Mr. Carnahan, and we went to Salinas and visited him. We took lessons from Dr. McCallum on how to assay rubber in a piece of guayule stem by chewing it up, spitting the wood out and seeing how big a piece of rubber gum you had left in your mouth. This is a very effective assay method. We made an arrangement by means of which Cal. Tech. would work on the physiology and biochemistry of the guayule with the support of the Intercontinental Rubber Company. So our work was started in the fall of 1939. When the Intercontinental Rubber Company was taken over by the U.S. Government in March of 1942 our arrangement continued with the U.S. Forest Service and I became an agent of the U.S. Forest Service. When the U.S. Forest Service collapsed in 1946, and the Emergency Rubber Project collapsed in 1946, our work at Cal. Tech. continued to be supported by the Stanford Research Institute with funds supplied by the Office of Naval Research. In 1950 our program was taken over, of all things, by the Office of the Quartermaster Corps of the U.S. Army and was supported by the U.S. Army until 1958. I'll tell you in a little while what happened after 1958.

The obvious place to start with the physiology of the guayule is to find out why the accumulation of rubber in the plant is cyclical. Rubber accumulates very slowly during the spring and summer. Rubber is produced, makes up half to one percent of the dry weight that is produced during the spring and summer, with the exact amount depending on the age of the plant and some other factors. Total rubber per plant and percent of rubber in the plant increases rapidly during fall and winter. So, what is the basis for this cyclical behavior? Luckily, at Cal. Tech. we had at our disposal air-conditioned greenhouses that could be kept at different controlled temperatures and we used these greenhouses to attack this problem.

It turned out if one keeps plants continuously in the warm--like at 80° day and night--they grow vigorously and vegetatively, and produce lots and lots of flowers and new growth, accumulating rubber up to a level of not more than one percent, generally in the range of one-half to one percent of total dry weight. If, on the other hand, we keep plants at 80° during the daytime and keep them for 16 hours at night at 45° then they accumulate rubber rapidly. In a period of three months they go from one percent of rubber to five percent rubber, at the same time increasing in dry weight just as rapidly as they would have had they remained at high temperatures. So the obvious conclusion is that at high temperatures day and night, plants photosynthesize and the photosynthate goes into new growth. At low night temperatures, photosynthesis continues but a portion of the photosynthate is diverted into rubber making.

Our studies indicated that the moisture stress does not increase rate of rubber accumulation or total amount of rubber accumulated under the optimum temperature conditions. The optimum temperature conditions are just what I outlined--night

temperatures of 45°. Night temperature that is too low stops photosynthesis during the daytime and stops rubber accumulation. Optimum day temperature is in the range of 60-65° to 80°; it doesn't make any difference over that range of temperatures. However, we did find that moisture stress is effective in increasing rubber accumulation in plants that are grown under high temperature conditions where normally vegetative growth would occur. But the increase in percent of rubber contained in the plant is at the expense of total rubber produced because water stress does diminish rate of photosynthesis.

Now the second matter which we address ourselves to is the relation of mineral nutrition to rubber accumulation. We found that the greatest growth and the greatest rubber accumulation in plants grown outdoors (so that they grow vegetatively during the summer and accumulate rubber during the winter) were those that made the most growth in dry weight. This was done in the classical mineral nutrition experimental techniques. By the way, concerning the first matter of temperature: Effects of temperature on rubber accumulation are contained in a paper which you have Xerox copies of. The effects of nutritional treatments on growth and rubber accumulation are contained in another paper which you may also have. Those plants that receive large amounts of nitrogen and phosphate make the most growth and accumulate the most rubber. Deficiency of nitrogen nitrate or phosphate diminishes growth and also diminishes rubber accumulation. These results are not contradictory to those that were discussed yesterday, or perhaps the day before, which said that the fertilizer application to guayule in the field did not result in any increased rubber accumulation. I think it merely means that the soils which we used to grow guayule in during the Emergency Rubber Project were by and large soils of high fertility, such high fertility that the application of more fertilizer didn't result in any further growth or rubber accumulation.

We did further experiments at the Bell Ranch Nursery on the effect of light intensity on guayule growth and rubber formation. We did this by staking out 1/8-acre plots shaded with lath slats, cutting the light to 1/2, 1/4, 1/8, etc., of incident light intensity. The incident light intensity at the Bell Ranch Nursery may be taken as one, pure sunlight, not diluted by clouds. We found that the rate of growth of dry matter accumulation is directly proportional to the light intensity to the level of 1/8 of incidence of whole sunlight. Rate of rubber accumulation is similarly approximately linearly related to light intensity. So we have three important factors controlling growth and rubber accumulation in guayule. One is temperature, especially at night; the second is high nutritional status and the third is high light intensity.

Now I want to return to another matter which we have discussed or at least made sideswipes at during the past two days, and that is yield per acre. Everything that I could find by the end of 1947 about yield of guayule rubber in the fields is summarized in a review which luckily is printed and I have a copy of it. It contains all of the published data on yield of guayule rubber per acre available up to the end of 1947. The facts that I could glean at that time are as follows:

The highest yields ever reported were reported by A.C. Hildreth, whose picture is there on the back wall. Dr. Hildreth reported in India Rubber World in 1946 that he was able to get from plants directly seeded in the field and grown for two years 1200 to 1500 pounds of rubber per acre over the two-year period. So that's 600-750 pounds per acre per year. That's irrigated. The Emergency Rubber Project presented data to the Poage Committee (which was a Congressional committee that investigated guayule rubber and recorded matters to determine if our project should be continued). Emergency Rubber Project figures contained in the Poage report are that it is possible to produce 900 pounds of rubber per acre in two years with

irrigated plots. W.B. McCallum in 1941, in a published report, says that if you let guayule plants grow to the age of 10-13 years so that they're what he calls mature, that means closure of the canopy (all the ground covered with guayule leaves) then at that time and without irrigation they will contain 2400 pounds rubber per acre approximately. So you get 2400 pounds when you harvest them, say, after 10 years of unirrigated growth. The data presented by the Berstein Rubber Project to the Poage Committee says that if you do the same thing you get 2700 pounds of rubber per acre after a 10-13 year period. So those two reports are in close agreement.

I conclude that with the 1946-48 technology of guayule growing, it would be reasonable to expect under irrigated conditions and appropriate climate, and we'll hear more about where you can find appropriate climate when we talk about the indicator plots. It would be reasonable to expect a yield of about 500 pounds per acre per year over a four-year period, that is an increment of 500 pounds per acre per year over a four-year period. About 2000 pounds in four years would be reasonable. In order to raise this level, you would have to have new plants produced by selection and plant breeding. Now I want for a moment to compare these yields with the yields of Hevea brazilianusus, grown in Southeast Asia then and now. In 1946 and prior to the Second World War, the yields of natural rubber from Hevea in Indonesia and in Malaysia were under 300 pounds per acre per year. In 1974 the average yield in Malaysia was 1200 pounds per acre per year and the yield from the estate sector, that is the large plantings, as separated from the small holders who have two to five acres, is somewhat over 2000 pounds of rubber per acre per year. We know from the test trials of the Rubber Research Institute of Malaysia that we have varieties that yield 3000 pounds per acre per year on a large-scale planting basis. We know that our best variety stimulated with ethylene will consistently yield 6000 pounds of rubber per acre per year. So over the period from 1946 to 1974, yields of Hevea rubber have been increased about one order of magnitude. You might ask, "Where's this all going to stop?" Luckily we can calculate that. We know that about 2-1/2% of the incident visible sun's energy is converted into plant material, carbohydrates, under otherwise optimal conditions, good temperature, good mineral nutrition and high light intensity. We know how much energy it takes to convert a gram of sugar into a gram of isoprenoid rubber. We can calculate that were the plant to convert all of its photosynthate into rubber, the yield would be about 9000 pounds of rubber per acre per year.

As I said, we have with Hevea already gotten 6000 pounds of rubber per acre per year on a sustained basis. That leaves something over then for the plant to produce new leaves and to produce new roots and to grow a little. They don't grow very much; they don't grow in girth (get fatter). When you take 6000 pounds of rubber per year from rubber trees they really stop growing. The principle with guayule, which to my satisfaction is established, is that to get high yields you have to grow the plants with irrigation. The principal remaining question is what sort of a trade-off are we willing to make? To give it less water, get less photosynthate, get less rubber per acre over a period of years--a trade-off of less water for less rubber. We need to have really good data on the relation of total rubber production as a function of total water applied.

Now I want to conclude with one slight digression. One of the main things that I learned during the Emergency Rubber Project time was that nobody knew at that time how photosynthate is converted to rubber, to isoprenoids. Therefore, I set out to study this matter and worked out the pathway by which carbon in CO_2 and in sugar, the photosynthetic product of CO_2, is converted to rubber. This also is

summarized in a review of which I have a copy for you. This was all discovered by 1958 and I found then that there's nobody in the U.S. interested in the path by which CO_2 is converted to isoprenoids. There is only one place in the world that was interested and that was Kuala Lumpur, the capital of Malaysia. In 1960 that government invited me to go to the Rubber Research Institute of Malaysia and I have been a contracted consultant to the Rubber Research Institute of Malaysia since that time. Even during that period of time, which is only 15 years, we have been able to double the yield of rubber per acre per year from existing plantings. We have been able to shorten the period between planting rubber trees in the field and the time you can start harvesting them from seven years to three years.

So my total conclusion is that there is a lot that can be done with rubber plants by serious plant biologists and there remains a lot to be done for guayule.

Questions

Question: Yesterday I believe Mr. Lobenstein said that a plant reached its ultimate maximum production at about 11 years old. You were talking about 10-13 with irrigation, now beyond that point it goes, I mean it starts deterioration of the plant and then lowers the rubber extract that can be derived from the plant.

Answer: After the closure of the canopy, as we heard, the bottom branches start to die, just like they would in a tree. The branches aren't getting any light anymore. When the branches die the rubber is decomposed probably nonbiologically because rubber plants don't have any enzymes to chew up rubber; it has to be done by spontaneous oxidation and so forth. But the answer is yes. After the closure of the canopy, after about 10 or 12 years in the wild, total rubber per acre starts to decrease.

Question: Then on your total amount that you were talking about at that time, were you referring not to harvest until the plant was about 10 years old?

Answer: I was talking about plants that are left in the field till they're 10 to 13 years old; at that time they have 2400-2700 pounds per acre. I didn't mean to imply that there is any sensible reason for growing guayule on a 10-year cycle. It seems to me, just think how awful that is, if you're going to grow guayule on a 10-year cycle and get 2400 pounds per acre after 10 years, you've only got 240 pounds per acre. That's no way to go; that's not an economic return per acre for anybody.

Question: Where did Dr. Hildreth do his work on his seedlings?

Answer: I think he must have done it in Salinas because I'm sure he didn't do it in Cheyenne. Do you know, Ben? It was done in Salinas. Dr. Hildreth was in charge of the USDA Experiment Station in Cheyenne and he was sent to join the Emergency Rubber Project for a period during the war, and therefore my remark about Cheyenne. He returned to Cheyenne, by the way.

Question: Did you try real high temperatures up above 100°?

Answer: No, I grew plants outdoors in Pasadena for a wide variety of reasons, and there the temperatures in general don't get over 100°. But we did experiments at the Bell Ranch Nursery near Indio. I visited the Bell Ranch Nursery one day a week for two years. The temperatures there got up to 120°. Guayule grows fine at a day temperature of 120° provided it's watered.

Question: Is anything known about the hormonal mechanism or other chemical mechanism for turning on the biosynthesis process?

Answer: No. It's my conclusion that it isn't anything complicated like a particular hormone. I conclude that the genes for producing the enzymes to make rubber are turned on by low temperature, and of course there are lots of genes that are turned on by low temperature. As Dr. A.J. Haagen-Smit will reveal to us, the genes for making the precursors for isoprenoids are turned on at all times in guayule, because they make a wide variety of other isoprenoids. I should mention also that for example in our experiments on the effects of temperature on rubber production, I also determined the total resin by extracting plants with acetone (total acetone solubles). Those remain constant throughout the whole range of temperatures. Those resins, as we saw are in part isoprenoids and in part fats. But anyway, genes for making the isoprenoids component of resins apparently are turned on even at high temperatures. I'm sure, Joel, that at the back of your mind is the question of whether one can diddle with the hormones of guayule in the way that we have with Hevea (application of ethylene to double or more than double rubber production). I see no reason to think that anything like that is possible with guayule because what we do with Hevea is effect the genes that have to do with the clotting mechanism that makes the latex clot and stop flowing. We turn off the genes for making the clotting mechanism.

Question: (Hugh Anderson) James, I don't know much about any rubber trees but I do remember reading that it took 10-12 years before they are tapped. What have you brought it down to now?

Answer: As I said a moment ago, the conventional wisdom says it's seven years from the time you plant the tree in the field until you can start tapping it. That is British conventional wisdom, and like all conventional wisdom, it's not right. We have shown during the last five years that you can cut the time to three by such simple techniques as watering the plants when you transplant them to the field, and further achieve a great reduction in this downtime by planting the plants in polyethylene bags so you don't bare roots when you plant them. You plant the entire bag in the field and then water it. So the time now is three years from the time you start planting in the field until you start tapping. When you start tapping you get an initial yield of 1000-2000 pounds per acre per year.

Question: (Robert Dennis) What was the method of ethylene application and what rates are used? We have been doing some of this with the sugar beets this past year here in Arizona.

Answer: (Bonner) What we use now is ethrel. We have used ethylene, put the plant inside a polyethylene bag and put some ethylene in, but that's too vigorous. It makes all the leaves fall off for one thing and makes latex flow out of every insect bite in the plant--and so that's not very good. What we do is use ethrel dissolved in ethlene glycol and dissolve that in palm oil; then paint that on the tapping panel with a two-inch wide brush, strip around the tapping panel, and the tapping panel generally goes half-way around the tree. We repeat that treatment (.1% ethyl in palm oil) once every two months. The cost is about 25 U.S. cents per acre per year and it, as I said, at the very least doubles the yield by increasing the length of time during which latex flows to the topping cut. Now please tell me what you found with the sugar beets; I don't quite see what the effect on sugar beets should be.

(Dennis) In the case of sugar beets our work followed that in Colorado, Great Western Sugar, in which ethylene gas, soil-injected, using a couple of pounds per acre and their results indicated an increased sugar production. In our case we had

many tests, no statistically significant increase, but the trend was there. More sugar with this ethylene application was the result, in the rows that were near to the place of application of ethylene.

(Bonner) That's extremely interesting and perhaps I shouldn't write off ethylene treatments of guayule. With guayule, obviously, as with sugar beets, the situation is complicated by virtue of the fact that you don't want the leaves to fall off. Ethylene is an excellent defoliant. The upper limit of the concentration of ethylene that we can apply to Hevea is determined by the fact that you don't want to apply enough so that it gets up the trunk to the leaves and makes them fall off. The mode of treatment of sugar beets is arranged also to not cause defoliation. Right? Ground injection.

(Dennis) The plants have a canopy of 10 to 12 inches at the time the ethylene is applied in the soil and it is supposed to move rather great distances horizontally in the soil. So it's possible that it might work with guayule, applied at a certain, right time.

SOIL-PLANT RELATIONSHIPS - GUAYULE

Omar J. Kelley
Co-Director, Crop Improvement Research Center, Suweon, Korea

In order to understand the soil-plant relationships of guayule, one needs to know something about the root system of the plant. By the term soil-plant relationships, I include the word water or namely soil-water-plant relationships, since the water characteristics of the soil play such a dominant role in the overall relationship.

Muller[4] gives a very good description of the root development of guayule under a wide range of conditions. He describes guayule as a single stemmed shrub reaching two to three feet in height. Under native conditions the roots form a modified taproot but this is not true under cultivated conditions. He points out, as most of us who have worked with guayule know, that the species is not a good competitor in its early life stage. He believes the modified taproot develops under native conditions due to the availability of moisture being present in only the top couple of feet of soil. If more moisture is available, more competitive plants will move in and prevent the establishment of guayule. With the limited water available, guayule will establish itself and then as water supply runs out it will go into dormancy for long periods of time--often with its complete root system at moisture levels below the wilting point. As an example, Muller[4] cites six-month-old seedlings surviving three months of severe drought. Further it has been stated that "there are records of places in Mexico where essentially no rain has fallen for several years but when the rains came plants picked up and were active in a day or two."

Figure 1 shows the root system of a native guayule plant. Notice the absence of a typical taproot and the massive lateral roots in the first two feet of soil. Figure 2 shows the root system of 17-month-old cultivated guayule plants where plants on the right side were missing. Notice how well the root system develops vertically when there is subsoil moisture, also how it develops laterally where there was no competition. These figures give a good indication of how readily the root system

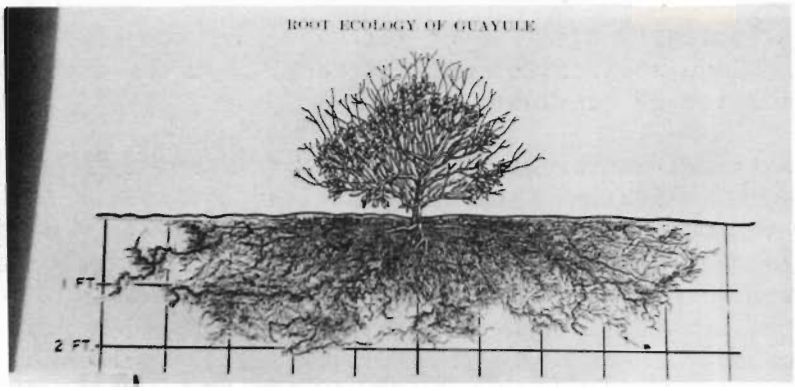

Figure 1. Native guayule about 30 years old in Ector stony loam in Brewster County, Tex. - From Muller[4]

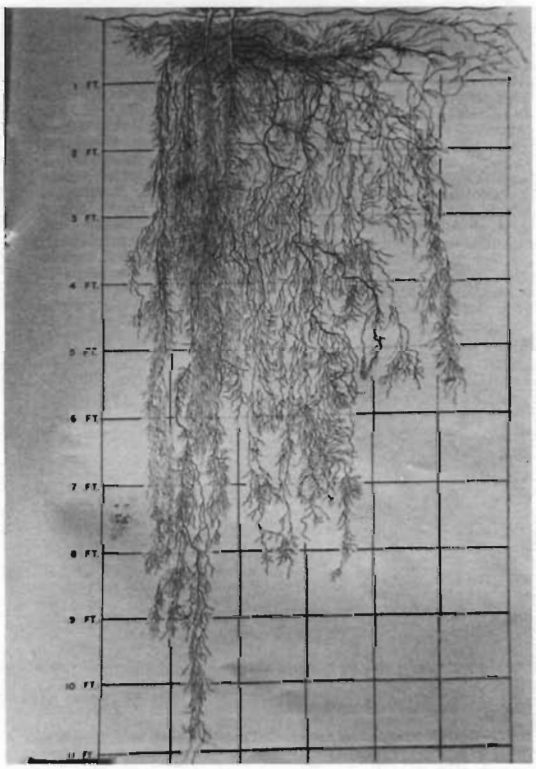

Figure 2. Seventeen-month-old plants lacking neighbors on right but closely crowded on the left. Note the great lateral spread into unoccupied soil and the decrease of penetration with increased spread. - From Muller[4]

of the guayule plant can adjust to soil moisture conditions. Figure 3 shows the root system of a seven-month-old nursery plant growing in Coachella loamy sand near Indio, California. The surface foot of loamy sand is fully occupied by roots, but

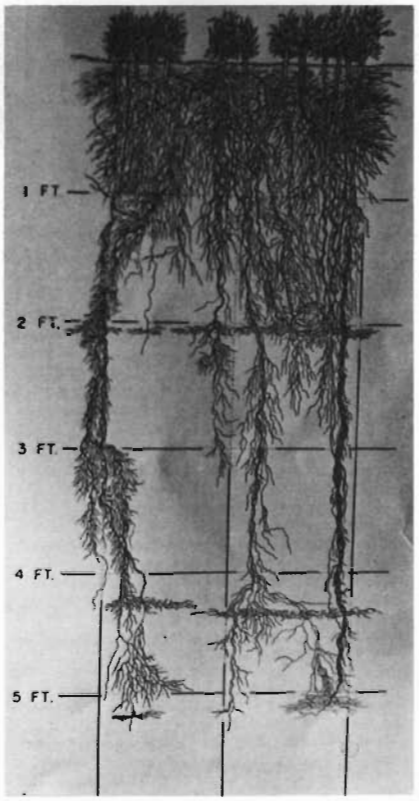

Figure 3. Seven-month-old nursery plants of guayule in Coachella loamy sand near Indio, Calif. Note the concentrations of feeder roots in horizontal layers corresponding to veins of clay and silt and the aggregation of principal roots in an old root channel on the right. From Muller[4]

roots become progressively more sparce as the almost pure sand is entered. The lateral growth of roots at the 24-inch and 52-inch depth represents a concentration of feeder roots in horizontal layers of clay and silt that is typically found in desert sands. This again is evidence of the ability of guayule roots to readily move into areas of more available water. The lack of root growth in the sand is attributed by Muller[4] to lack of water. Figure 4 shows younger plants indicating the same phenomena. Guayule does, however, have the ability to grow under a wide range of moisture conditions if competition from other plants is removed during the early growth period. Plant roots have been found to penetrate the soil beyond the 20-foot depth.

Due to the fragile nature of the guayule seedling and its poor competitive ability, nearly all guayule grown under the Emergency Rubber Project was transplanted from nurseries. (While some work was done on direct seeding of guayule, more information is required before direct seeding could be recommended as a commercial practice.) Thus, considerable work was done on the soil-water-plant relationships

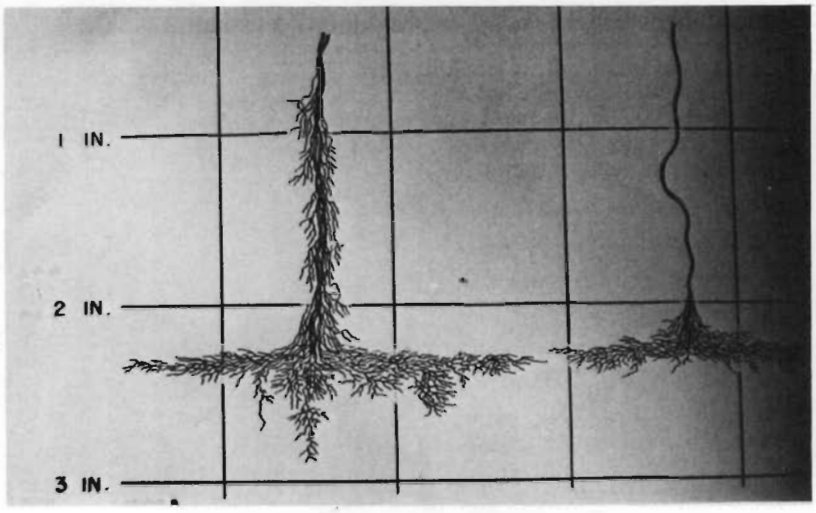

Figure 4. Guayule roots passing from dune sand to clay veins. Note the absence of branches or their effective suppression in the sand and their ramification in the horizontal clay layer. - From Muller[4]

of nursery-grown guayule and the transplantability of the plants grown under a wide range of treatments. Only the highlights of these studies will be reported here. The details can be found in guayule literature, part of which is cited here.

One experiment conducted on the effect of moisture stress on nursery-grown guayule with respect to the amount and type of growth and growth response on transplanting[3] gives some very interesting and valuable information on nursery conditions required for good transplantable plants. In this experiment five moisture stress levels were studied ranging from very low moisture stress throughout the plants' growth to a treatment that received no irrigation after the plants were well established. The moisture stress levels increased from treatment #I to treatment #V as indicated. The study was also conducted at two fertility levels but these had little or no effect of transplantability.

The type of growth produced by the several treatments differed markedly. Those plants grown under conditions of low moisture stress produced a large vegetative growth and flowered profusely, while the opposite was true for plants grown under high moisture stress. The plants of treatment V made only a fraction as much vegetative growth as those of treatment I, and only a few of them flowered at all during the summer. There were striking differences in the color and other physical characteristics of the plants. Those grown with the larger amounts of water were very succulent, brittle, and their leaves were light green in color; in contrast, those grown under the higher moisture stresses were shriveled, tough, and in leaf color a bluish-grey. The bluish-grey color was thought to be indicative of plants that are in good condition for transplanting, regardless of how they were hardened off.

Since the plants produced by the several moisture treatments differed so greatly in top growth, root studies were made on the two wettest and the driest treatments. There was little difference in the depth of root penetration. In all cases there was profuse root development to the 42-inch depth, and only rarely below the 48-inch depth. There were fewer lateral roots near the surface of treatment V, but the authors reported this was expected due to the very high moisture stress at this depth for most of the summer.

The effect of the differential moisture stresses on the rubber and resin content was also reported. Table 1 shows this information. The rubber content of both the tops and roots were drastically affected by the different moisture treatments. The rubber percent varied in the tops from a low of 0.14 to 1.15 and in the roots from 0.10 to 2.21. Thus in the roots the rubber percentage was over 20 times higher in the plants grown under high moisture stress. The authors report that these and other studies conducted in this experiment show that "in general, low moisture stress leads to enlargement of the tissues of the plants, with corresponding increases in rubber-bearing capacity; high moisture stress leads to the accumulation of the products of photosynthesis." They also stated, on the bases of their observations and data that "it would not be unreasonable to expect that a maximum yield of rubber might be obtained by growing guayule under low moisture stresses for a period of time long enough to produce a large shrub with a high potential rubber-bearing capacity and then subjecting it to a period of high moisture stresses in order to increase the percentage of rubber."

Table 1. Rubber and resin analyses. From Kelley et al.[3]

Moisture treatment	Plants sampled Sept. 28, 1943				Plants sampled Feb. 9, 1944	
	Rubber		Resin			
	Tops %	Roots %	Tops %	Roots %	Rubber %	Pounds rubber per acre
I	0.14	0.10	3.08	1.15	2.5	360
II	0.17	0.32	3.10	1.93	3.2	354
III	0.19	0.37	3.60	2.23	2.9	310
IV	0.17	0.39	3.90	1.95	3.7	333
V	1.15	2.21	4.45	3.88	8.0	348

Growth Response After Transplanting

For all plants that are grown in nurseries for transplanting, including guayule, the most important criterion of nursery practices is the ability of the plants to resume growth quickly and to survive when set into the field.

The effects of previous moisture treatment upon the after-transplanting growth responses of the nursery stock grown in the experiment referred to here were studied in an extensive transplanting program. Nine transplantings were made at intervals during the period from September, 1943 to July, 1944. Detailed data are given for each date of transplanting on the resumption of growth following transplanting. Data on new growth was noted a few days after transplanting and continued for several months, or until it was obvious that those that had not renewed growth were dead. Only a summary is reported here, namely the percentage of plants showing new growth at the latest counting for the first eight transplantings. This data is shown in Figure 5. Note that equally satisfactory growth resumption of the plants of treatment V occurred at all seasons. Regardless of the date of transplanting, 91 to 93% of these plants grew, and in all cases, the authors report, they resumed growth more quickly than plants of any other treatment. They also report that with increasing elapsed time between the cessation of irrigation and the date of transplanting, the growth responses of the plants grown under the low and medium moisture stresses of the first four treatments more and more closely approached those of the plants grown under the very high moisture stresses of treatment V. It was not until

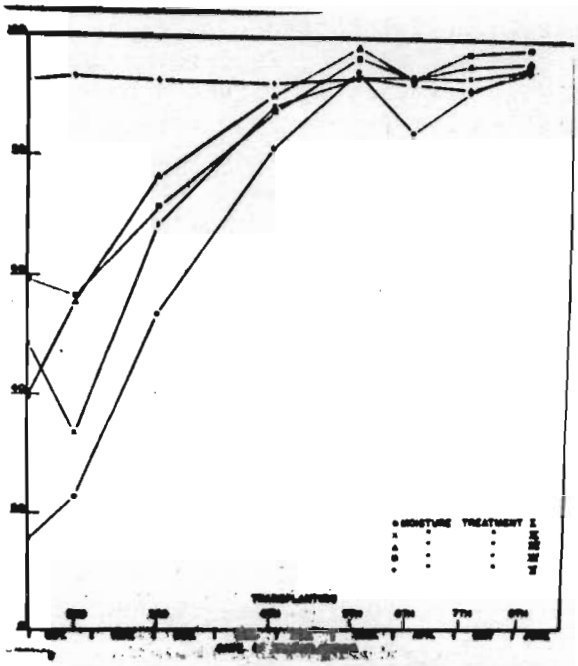

Figure 5. Percentages of plants showing new growth at the latest counting for the first eight transplantings. - From Kelley et al.[3]

the fourth transplanting, however, that the plants of the first four treatments survived transplanting at all satisfactorily. At the fifth they appeared as good as treatment V. The results of treatment V indicate that nursery plants can be grown that will survive well when transplanted any time of the year, provided soil moisture and temperature conditions are favorable.

Effect of Moisture Stress on Growth and Rubber Content

Where temperature conditions are suitable for good growth of guayule, soil moisture is probably the most important factor affecting growth and rubber accumulation in the guayule plant. Under desert conditions guayule growth is very slow and is controlled almost entirely by the available water supply. When water is amply available guayule enters a lush and vigorous growth stage. Little or no rubber is laid down during this stage of growth. As the available water becomes less and less available guayule growth becomes less and less vigorous until water is no longer available or only slightly so and then guayule becomes dormant. While this much is accepted as known facts, there is really little exact information on the effect of varying moisture stresses on guayule growth and rubber production over a long period of time. The Emergency Rubber Project did not last long enough to obtain such information. To be sure, considerable information was obtained on the effect of different moisture conditions for short periods of time, and much of this is very interesting. It also provides background for various hypotheses.

Hunter and Kelley,[1] working with one-year-old transplanted shrub, initiated five moisture treatments on guayule growing on two different soil types in the San Joaquin Valley in 1944. One was on a Delano sandy loam known as the Sill tract and the other was on a Sorrento silty clay loam known as the Isom tract. At the beginning of the experiment all the plots except those of treatment 5 were given heavy and prolonged irrigation to wet the soil to the "field capacity" to a depth of at least eight feet. Treatment 5 received no irrigation throughout the study and

treatments 2 and 3 were progressively at increasing stresses between treatments 1 and 4.

The Delano sandy loam (Sill tract) held most of its water at very low moisture tensions while the Sorrento silty clay loam (Isom tract) held only about one-fourth of its available water in the low moisture tension range, the remainder being more equally divided up to tensions at the wilting point.

Figure 6 gives the yield of shrub and rubber and the percentage of rubber and resin at four sampling dates. Note at the beginning of the experiment there are no differences in any of the measurements.

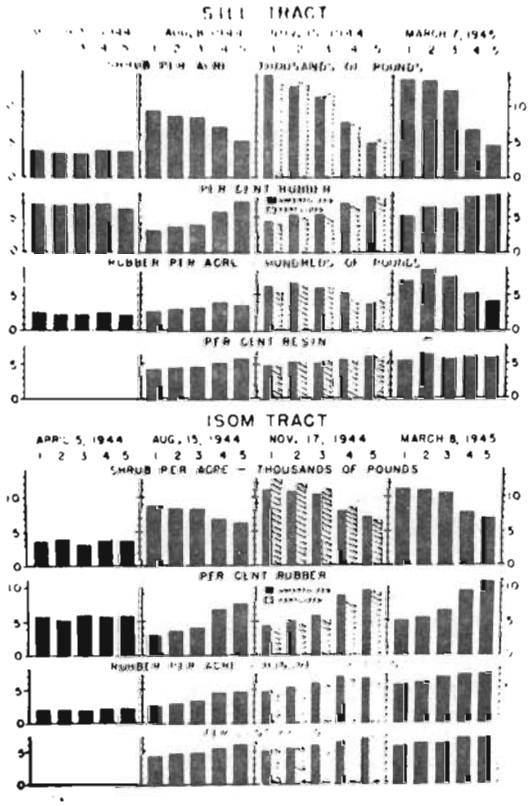

Figure 6. Yield of shrub and rubber and resin content at four sampling dates of guayule grown under five different moisture treatments on Sill and Ison tracts. - From Hunter & Kelley[1]

By August significant differences were beginning to occur. At this time the data show a reciprocal relationship between the yield of shrub and the percentage of rubber. At this time the response of the plants to the five irrigation treatments were very similar on the two soils. On the low moisture stress (high moisture) plots the percentage of rubber decreased during the period between the initial and August shrub sampling. This was thought to be due to the dilution effect of new growth having very low rubber content. The driest plots, treatment 5, showed a slight increase in content. All plots showed an increase in shrub weight, with the

low moisture stress plots giving the greatest gains. The increase in rubber yield per acre was greatest on the driest treatments, namely 140 pounds for treatment 5 on the Sill tract and 240 pounds per acre on the Isom tract. The respective yields for the low moisture stress plots were 24 and 52 pounds. By November sampling, it was evident that the drier plots on the Sill tract were producing very little additional shrub, while those on the Isom tract were continuing growth. The wetter treatments in both tracts continued rapid growth. The rubber content still remained higher with the drier treatments. By March of 1945, nearly a year after the initiation of the experiment, there had been little or no additional growth on the drier plots of the Sill tract, and while the absolute rubber content remained highest on the drier plots, the relative increase over the previous sampling was greater for the three wetter treatments. Thus the total rubber production was highest for treatment 2 followed by treatment 3 and then treatment 1. For the Isom tract the relative increase in shrub production was less on the wetter plots compared to the drier plots and rubber content continued to increase on the drier plots. Thus, the drier plots produced more total rubber.

The authors found it difficult to fully explain the results of this experiment. They felt that the poorer growth of shrub and lower increased rubber content of the drier plots on the Sill tract may have been due to the soil water holding characteristics of the sandy loam soil compared to those of the silty clay soil on the Isom tract. They indicated that the plants on the Sill plots either had ample water for lush growth or were quickly subjected to such high moisture tensions that they went into dormancy with little or no time for increasing rubber content, while on the Isom tract the plants gradually experienced increasing moisture stress, stayed in a reduced vegetative growth, but continued to grow and produce rubber. Furthermore, the soil on the Isom tract held more water than the soil on the Sill tract, so these had more water for growth under the drier treatments. While these data do not conflict with the general principle that more rubber is laid down under conditions of relative high moisture stress, they do indicate that there are stresses above which rubber will continue to accumulate.

Another study[2] conducted on what was originally nursery stock gives additional information on the soil-water-plant relations in guayule rubber production. Late in 1943 it became apparent that the further planting of guayule as a war-emergency source of rubber was to be drastically curtailed, and that there was considerable nursery stock that would not be used for transplanting. Four nurseries were chosen for these studies. Two, the Bell and Whittier Nurseries, were located in the Coachella Valley and two were located close to the Pacific Ocean near San Diego at San Mateo and Carlsbad. The Bell Nursery is located on very sandy soil and the Whittier Nursery on a loam, both in a hot and dry climate. The Carlsbad Nursery was located on a sandy loam and the San Mateo Nursery on a loam soil, both having lower temperatures, lower light intensity and higher relative humidity than the Coachella area. In each nursery the plants grew in rows seven inches apart in seven-row nursery beds. Before thinning there were 10 to 20 plants per linear foot of row.

The treatments consisted of six spacing treatments with decreasing densities from treatment 1 through 6. Number 1 was left unthinned on the original stand. Moisture treatments were three, with treatment A receiving irrigation only when the plants appeared to be dying from drought, with C receiving sufficient water to keep the plants growing vigorously at all times, and B in between A and C. There were several fertilizer treatments, but with the exception of the Bell Nursery which was essentially pure sand, the #1 or no-added fertilizer treatment produced the most rubber. At the Bell and Whittier Nurseries one-half of the plants were clipped and the other half not clipped or left in original state. Table 2 gives data on rubber

Table 2. The status of the guayule plants with respect to percentage of rubber, tons of shrub per acre and pounds of rubber per acre at the various nurseries at the initiation of the experiment. - From Kelley et al.[2]

Nursery	Sampling date, 1944	Rubber %	Tons of shrub per acre	Pounds of rubber per acre
Bell	Jan.	2.37 ± 0.49	3.60 ± 0.19	170 ± 14
Whittier	Feb.	3.21 ± 0.26	4.08 ± 0.18	225 ± 13
Carlsbad	April	8.26 ± 0.10	1.71 ± 0.09	283 ± 17
San Mateo	April	7.09 ± 0.12	1.96 ± 0.14	280 ± 23

content, tons of shrub per acre and pounds of rubber per acre at the beginning of the experiment at each location. The major differences are between the two nurseries located on the coast and the two located in the Coachella Valley. Rubber percentage was much higher and production of shrub was much lower on the nurseries located near the coast.

While there is much interesting data from this experiment, only a summary table of the highest rubber yielding plots is presented here. This data is shown in Table 3. In all cases the increased density of stand resulted in the greatest rubber production. Since the maximum age of the plants at harvest time was only 21 months this might be expected. Close to the coast the drier treatments produced the highest rubber per acre. In the hot climate of the Coachella Valley with the lighter soils the wettest treatments produced the most rubber. (This is consistent with the data reported earlier on the sandy soil of the Sill tract.) In only one case did added fertilizer increase rubber production and that was in the very sandy infertile soils at the Bell ranch. Clipping reduced yields at both of the nurseries where it was studied.

Table 3. Tons of shrub, percentage of rubber and pounds of rubber per acre for the factorial treatment which produced the highest yield of rubber per acre at the various nurseries. - From Kelley et al.[2]

The nursery plants were all 10 months old when the experiment was initiated. They were harvested when 19 months old at the Bell and Carlsbad Nurseries, 21 months old at the San Mateo Nursery and 23 months old at the Whittier Nursery. The highest yield of rubber per acre was 1336 pounds in 21 months at the San Mateo Nursery. During the period of time that this nursery was under experimentation, namely 11 months, the average monthly yield of rubber was 96 pounds, or a total of 1056 pounds in 11 months.

From the experiments mentioned here and others conducted on the guayule plant it is quite apparent that guayule will grow on many types of soil. It appears to do best on loam or clay loam soils, particularily those soils that have a high water holding capacity and where the water is held in the soil over a wide range of moisture tensions. In most soils native fertility seems to be sufficient. In only a very few highly infertile soils did added fertilizer improve total rubber production and too much fertilizer can lower total production. Within any given environmental condition and the varieties used, available water seems to be the most important single factor affecting the growth and rubber production of guayule. It will not tolerate a waterlogged root zone, but produces under wide conditions of soil moisture stresses in the drier ranges. From the data available, it appears that an environmental condition (including moisture availability) that will provide for rapid establishment of the crop with alternate periods of hardening-off and good vegetative growth would provide the best conditions for maximum rubber production per acre. Since guayule is a good competitor, once it is established, it should be a valuable crop in the more marginal areas due to low moisture availability. Much more information is needed to predict the exact conditions required for maximum growth under varying conditions of soil type, available soil moisture and differing climatic conditions.

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Questions and Answers

Question: (Ken Emerson) Most of the discussion of this meeting has centered around propagating guayule from seeds, and at the same time it has appeared necessary to do at least one transplanting on these. I've wondered, since I know that some work was done with cuttings, what you could say about the relative economics of using cuttings rather than seeds, and rooting from cuttings. Might cuttings not be a way to go in some cases?

Answer: (O. Kelley) I probably am not the best person to answer that question; I suspect that Dr. Bonner and some of the others would be better, but my reaction to it would be that from an economic standpoint this would not be a good way to go because there is a lot of labor involved. Everything that I've seen on guayule indicates that it is a very poor competitor, especially in the seedling stage. If you have to root it, obviously you can do it, but from an economic standpoint I don't think this would be the way to do it. It's easy to grow guayule seedlings if you can keep the competition out. If you want the cuttings, I think you'd have even more difficulty than you would with the seedlings.

Comment: (H. Benedict) As far as I know, none of the group of about 10 plant physiologists working at Salinas investigated cuttings.

Dr. Haagen-Smit, from the California Institute of Technology, has two very short papers he wants to present in discussing some of the unusual organic compounds that are produced in the guayule plant.

In 1941-42 we were asked to make an analysis of the volatile components of the guayule rubber, and that was a most tedious work and vitally dependent on the luck and the skill of the operators. In 1960 Dr. Nimmo built a gas chromatography apparatus, one of the first made. We thought it would be nice to see if we could improve upon our work of 1942. What we did in 1942 took us a few months. Now we could do it practically in a morning.

This slide gives you the results of some of the chromatography analysis of several variations of different strains of the Parthenium we picked up in Salinas. This was kind of a sad business to go to Salinas, and only find about eight of the strains. You see that I listed here the various terpenes, the α-pinene, for example, is about 55% in this strain A48116, whereas there is 18% in 593. Now all those different terpenes, some of them bycyclic, some of them monocyclic and some acyclic compounds, have different percentages in the different strengths. I put up only two so as not to confuse the picture. What is interesting is the great difference between the strengths. For example, in the case of the sabinene and the β-phellandrene, which is practically absent in A48116, it is about 15-20% in the 593. I was also able to find in Salinas one plant of the Parthenium stramonium and that one had a completely different picture, more like 593. One of the very interesting things was that the myrcene, the acyclic terpene, was about 20% of the total terpene fraction. I just want to bring this up because it's such an interesting kind of study for finding out the biosynthetic pathways by which the various terpenes are formed. Not only of course the monoterpenes, but the sesque- and higher terpenes. This work was originally done to see if there were valuable compounds that could increase the economic value of the guayule cultivation. I still think that there is some promise that probably would make some pocket money, but some of those compounds like myrcene and ocimene, and some of the others, are very hard to come by synthetically. Perhaps industry may find some use in making medicinals or some other compounds. I just thought I would bring this to you so that if this whole project is restored, somebody could really go to work and do an extensive job on the analysis of the by-product.

CLIMATIC RELATIONSHIPS IN THE GROWTH AND PRODUCTION OF GUAYULE

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Introduction

Discussions of climate in relation to plant growth and plant production usually refer to effects of light, temperature and rainfall. When considering light, three phases are important: intensity, duration (day length) and quality (wavelength). Rainfall generally exerts its effects on the available soil moisture. For this reason there is a possibility that material discussed in this paper may repeat material presented in the previous paper.

In this paper I propose to present studies that have been conducted to indicate the climatic requirements of guayule and then illustrate the effects with some experiments that have been conducted under more or less controlled conditions. All of the experiments were carried out in the greenhouses at Salinas, California between 1942 and 1949 under the auspices of the Emergency Rubber Project, Stanford Research Institute under contract to the United States Navy, and the Agricultural Research Service.

Methods

Specifically three greenhouse studies will be considered. One, a factorial experiment in which five-month-old guayule plants were grown for an additional five months in two levels of light intensity, two levels of soil moisture and two levels of temperature, and all possible combinations. In a similar study the plants were grown under two levels of nitrogen availability in nutrient solutions, two levels of light intensity and two levels of temperature. The different temperatures were maintained by growing the plants in separate greenhouses, one of which was kept above 70° during the night but rose to as high as 90° during the middle of bright, sunny days. The average temperature in this house was about 75° according to thermograph records. The other greenhouse was cooled to 70° during the day and kept above 50° at night, with about a 60° average. The cooling was accomplished through the use of evaporative coolers, refrigerated coils, plus water flowing over the house during the sunlight hours.

In each of the greenhouses a frame was constructed over which commodity cloth was suspended which transmitted about 60% of the incident radiation. The shaded and unshaded areas provided the two different light intensities.

The levels of soil moisture were provided by growing the plants in 1/2-gallon glazed crocks containing a weighed amount of soil whose field capacity was known along with its wilting point. To maintain a high moisture level the plants were watered daily and weighed once a week to insure that overwatering was not occurring. The low soil moisture levels were achieved by allowing the soil to dry out until its wilting point was approached as indicated by the weight of the crocks.

The complete and minus nitrogen nutrient conditions were maintained by growing the plants in sand culture and adding complete and minus nitrogen nutrient solutions as described by Hoagland.

The second experiment to be discussed involves growing the plants in different soil temperatures but at the same air temperature. The plants were grown in soil in cans which were immersed in tanks of water maintained at the desired temperatures.

The third study involved growing the plants in alternating periods of low and high moisture stress. In this experiment the plants were grown in large boxes of soil. The soil moistures were maintained at the desired stresses by measuring their electrical conductivity through Buoyucas blocks.

Results

Light: Guayule is native to or has been successfully grown from about 22° to about 42° N and at altitudes ranging from sea level to about 7000 ft. It has been grown in the overcast coastal valleys of California, such as around Salinas and in the semidesert high-sunlight areas of Mexico. Thus it would seem that light intensity as it normally occurs is not a limiting factor as far as guayule growth and production is concerned. However, the results of the factorial experiment described above indicate that under certain circumstances a reduction in light intensity can markedly reduce the growth and especially the rubber production of guayule. The data in Table 1 presents the percentage of growth and rubber production of the plants in 60% of full sunlight with those in full sunlight in the Salinas greenhouses. Thus at the higher temperature the plants in the shade weighed only about half those in full light intensity, while at the lower temperature they were only about one-fourth the weight. As far as rubber production is concerned, the plants in the shade produced only one percent of those in the sun. Table 2 shows the effect of reduced light on plants grown in nutrient solutions containing a high level of nitrogen. Here again reducing the light intensity greatly reduced the percentage and total grams of rubber produced.

The range in latitude over which guayule can be grown results in a wide range of day lengths. In all of these latitudes guayule blooms throughout the year if temperatures are high enough. This would indicate that guayule is an indeterminant plant as far as day length requirements for blooming are concerned.

I know of no studies that have been conducted on the response of guayule to different wavelengths of radiation. However, in its native habitat guayule is exposed to considerable variation in the relative amounts of short and long wavelengths of light because of the differences in altitude and moisture contents of the atmosphere. Hence guayule can tolerate changes in blue and ultraviolet radiation with different amounts of red and infrared.

Temperature: As indicated by the wide range in latitude and altitude at which guayule can be grown it has a fairly wide range of temperatures that it can tolerate. Generally speaking it is the lower temperature that limits the regions in which it can be grown. Under normal conditions guayule should not be grown where winter temperatures fall below 15° F. However, in areas where there are long dry autumns and gradually decreasing temperatures which produce an unusual amount of "hardiness" guayule can stand temperatures as low as zero. Guayule is rather susceptible to winter injury, especially if a sudden freeze occurs after a warm or a wet spell, such as a very cold autumn day following a late fall. Spring frosts following early warm spells can often injure guayule. In some instances guayule plants have been killed by freezes, and where this has occurred the rubber content of the shrub has completely disappeared in a few days.

While the lower temperatures are critical the higher temperatures are favorable for the growth of guayule. Thus it does well at temperatures of 90° F. However, the highest yields of rubber occur during periods of high daytime temperatures followed by low night temperatures. Average temperatures should be above 75° for optimum growth and rubber production and should never average below 60° F. Such low temperatures can result in slow growth and even some mortality.

Table 1. Ratios, in percent, of guayule plants grown in shade to those grown in full sunlight with ample moisture.

	Leaves	Stems	Roots	Total
Dry Weight				
75° F.	57	66	27	52
60° F.	32	32	15	27
Rubber Percent				
75° F.		15	20	
60° F.		5	24	
Rubber Grams				
75° F		1	1	1
60° F		1	1	1

Table 2. Ratios, in percent, of guayule plants grown in shade to those grown in full sunlight in a high nitrogen nutrient solution.

	Leaves	Stems	Roots	Total
Dry Weight				
75° F.	45	44	19	38
60° F.	56	54	32	47
Rubber Percent				
75° F.		10	14	
60° F.		5	22	
Rubber Grams				
75° F.		6	3	4
60° F.		4	5	4

Tables 3 and 4 show the responses of guayule plants to mean temperatures of 60° and 75° F. When the plants were grown in soil of different moisture contents the plants in the lower temperature made less growth than in the higher temperature, with the exception of the roots at the higher moisture content. The rubber percentage in the stems at the low temperature was about 40 percent higher than in the high temperature, although in the roots the percentage of rubber was lower in the low temperature treatment. The actual yield of rubber in grams per plant was also lower in the lower temperature than in the higher temperature.

In sand culture (Table 4) the lower temperature reduced the growth of the plants as was true in soil but also the rubber percentage in the stems as well as in the roots. In other words, the results of both soil and sand culture studies show that at temperatures averaging 75° the rubber production of the plants was about 40 percent higher for soil grown plants and about 200 percent higher for sand cultured plants than in temperatures averaging about 60° F.

Table 3. Ratios, in percent, of guayule plants grown at about 60° F. to those grown at about 75° F. in full sunlight but under different soil moisture contents.

	Leaves	Stems	Roots	Total
Dry Weight				
High Moisture	80	68	102	83
Low Moisture	66	50	83	68
Rubber Percent				
High Moisture		137	74	
Low Moisture		141	95	
Rubber Grams				
High Moisture		93	75	82
Low Moisture		73	79	75

Table 4. Ratios, in percent, of guayule plants grown at about 60° F. to those grown at about 75° F. in full sunlight but under different nitrogen levels in nutrient solutions.

	Leaves	Stems	Roots	Total
Dry Weight				
High Nitrogen	87	60	77	77
Low Nitrogen	68	54	80	60
Rubber Percent				
High Nitrogen		42	40	
Low Nitrogen		55	54	
Rubber Grams				
High Nitrogen		22	31	25
Low Nitrogen		29	43	35

The results presented have related only to air temperatures with soil temperatures about the same. Studies have been carried out on the responses of guayule plants to different soil temperatures in a constant air temperature. Table 5 shows the dry weights and rubber content of plants grown in soil temperatures ranging from 45° to 95° F. in an air temperature of 75°. The maximum stem and leaf growth occurred at 85° while the maximum root growth was found at 65°. The rubber percentage of both the stems and roots was highest at the lowest soil temperature and decreased as the temperature increased. The maximum amount of rubber per plant was produced in the stems at 85° and in the roots at 65°. There was no significant difference in the total amount per plant from 65° to 85° F.

In this study a soil was used which provided a continuous rate of growth throughout the experiment. In another trial a soil was used which gave rapid

Table 5. Dry weight and rubber content of plants grown in different soil temperatures with an air temperature of 75° F.

	Soil temperature in degrees F.					
	45	55	65	75	85	95
Dry Weight						
Leaves	5.1	8.4	23.2	30.6	35.4	27.8
Stems	2.6	5.7	13.4	18.1	25.0	16.7
Roots	2.2	3.6	7.9	6.8	6.5	5.2
Total	9.9	17.7	44.5	55.5	66.9	49.7
Rubber Percent						
Stems	4.7	2.8	1.8	1.5	1.1	1.0
Roots	3.6	2.3	1.5	1.3	1.0	0.7
Rubber Grams						
Stems	.122	.160	.241	.272	.275	.167
Roots	.079	.083	.119	.088	.065	.036
Total	.201	.243	.360	.360	.340	.203

initial growth for the first few months than very slow growth the remainder of the test. In this instance the rubber percentage in the roots decreased between 40 and 70 degrees but then increased between 70 and 80 degrees. This stress of high temperatures applied when the plants were making little growth seemed to result in increased rubber formation. This would suggest that high soil temperatures per se do not reduce rubber formation but that there are interactions with other growth factors.

Rainfall: A minimum rainfall of about 15 inches per year is required for good growth and rubber formation in guayule. However, where temperatures are low such as some of the coastal valleys of California, satisfactory yields may be obtained with as low as 11 inches per year. Similarly more rainfall may be required in areas of higher temperatures. Distribution throughout the year is also important. Dry spells associated with cool temperatures seem to favor rubber accumulation. In certain areas rainfall during the warm summer months may favor disease infestation. It is generally recommended for dry land culture that there be ample moisture in the spring and early summer and also a dry period before the winter months. Such a dry period may favor rubber accumulation but it also develops frost resistance in the plants. If the rainfall exceeds 25 inches there is a tendency for large plants with a low rubber percentage to develop.

Some of the effects of varying soil moisture which is of course related to rainfall are shown in Tables 6 and 7a, 7b and 7c. When the plants were grown in high soil moistures regardless of the temperature the plants made better growth than in low soil moisture. However the effect was much less on the roots than on the stems and leaves. While a lower soil moisture resulted in poorer growth it did produce an increase in rubber content of the plants. This was true of both stems and roots at two temperatures. However the increase in rubber percentage did not compensate for the loss in dry weight and the rubber per plant was less in the low soil moisture treatment.

Table 6. Ratio, in percent, of guayule plants grown in low soil moisture to those grown in high soil moisture in full sunlight but in two different temperatures.

	Leaves	Stems	Roots	Total
Dry Weight				
74° F.	54	57	67	59
60° F.	45	42	55	47
Rubber Percent				
75° F.		163	104	
60° F.		168	133	
Rubber Grams				
75° F.		93	70	83
60° F.		73	73	73

Table 7a. Dry weight of guayule plants grown for fourteen months under different watering regimes.

	Duration of Treatment - Months						
	2	4	6	8	10	12	14
Stems							
A	1.3	4.3	17.2	23.5	29.1	36.9	63.6
B		3.3	14.3	23.6	26.5	35.0	54.8
C		4.2		20.2		28.3	50.0
D					29.1		40.9
Roots							
A	1.3	4.1	7.6	9.0	12.5	13.3	18.2
B		3.7	5.5	8.8	10.6	11.1	17.3
C		4.1		8.4		11.2	14.0
D					12.5		11.8

Values at end of dry periods are underlined.

Table 7b. Rubber percentage of guayule plants grown for fourteen months under different watering regimes.

	Duration of Treatment - Months						
	2	4	6	8	10	12	14
Stems							
A	3.3	3.6	2.0	2.7	2.5	1.4	1.8
B		5.2	2.7	3.8	3.4	2.2	2.3
C		3.6		4.5		2.6	4.0
D					2.5		3.5
Roots							
A	2.5	0.4	1.3	2.2	1.8	1.5	1.7
B		1.5	1.2	2.8	2.3	2.2	1.8
C		0.4		3.6		2.8	3.4
D					1.8		2.7

Values at end of dry periods are underlined

Table 7c. Rubber content in grams of guayule plants grown for fourteen months under different watering regimes.

	Duration of Treatment - Months						
	2	4	6	8	10	12	14
Stems							
A	.04	.15	.34	.63	.73	.52	1.14
B		.17	.39	.90	.77	.77	1.26
C		.15		.91		.74	2.00
D					.73		1.43
Roots							
A	.03	.02	.10	.20	.23	.20	.31
B		.06	.07	.25	.24	.24	.31
C		.02		.30		.31	.48
D					.23		.32
Total							
A	.07	.17	.44	.83	.96	.72	1.45
B		.23	.46	1.16	1.14	.98	1.57
C		.17		1.21		1.05	2.48
D					.96		1.75

Values at end of dry periods are underlined

Another study was completed in which guayule plants were grown under different irrigation regimes. The original design called for growing the plants for 16 months under the following conditions:

A. At a high moisture level throughout.
B. At alternating high and low soil moisture levels of two months duration, resulting in four moist and four dry periods and ending after a dry period.
C. At alternating high and low moisture levels of four months duration resulting in two wet and two dry periods and ending after a dry period.
D. Growing the plants for 10 months at a high moisture level followed by six months at a low level.

However, because of the termination of the work, the study had to be discontinued at the end of 14 months. This resulted in Treatment B ending after a wet period and Treatment C after only two months of the final dry period, Treatment C receiving only four instead of six months drought. The results on the dry weights of the plants are shown in Table 7a, the rubber percentages in Table 7b and the rubber per plant in Table 7c.

The two-month alternation treatment had almost no effect on the dry weight of the roots and stems. The plants in Treatment C and D had successively less dry weight than the controls. Table 7b shows that at the end of each dry period the percentage of rubber in the plants exceeded that of the controls. The results also show that during a wet period the percentages dropped. The highest rubber percentage at the end of the study was found in the plants on the four-month cycle, or Treatment C. Treatment D had the next highest percentage followed by Treatment B and the checks or the plants in continuous high moisture, as expected, had the least. As far as grams of rubber per plant are concerned, Treatment C far outyielded any of the others.

There is an interesting result noted in these data in relation to the growth and formation of rubber during the months from November to March or from the eighth to the twelfth month of the treatments. There appears to be slow-down in growth during this period but also there was no accumulation of rubber on a grams per plant basis. (The apparent loss is not significant.) This suggests that there may be some seasonal effect associated with the winter months (low light intensity perhaps or even day length) which interfers with rubber production. This observation led to a small study in which guayule seed were planted ten days before each equinox and each solstice and halfway between these dates. The plants were allowed to grow for three months when their dry weight was determined. Soil conditions and temperature were maintained as constant as possible throughout the study. The plants that emerged during the period from September 21 through December 21 made the poorest growth, while those that emerged between March 21 and June 21 made the greatest growth--that is, had the greatest dry weight. This difference may be related to light intensity at the different times of the year. With modern environmental control chambers it might be interesting to examine the effects of increasing and decreasing day lengths.

Nitrogen supply: While the availability of nutrients is not truly a climatic factor in the factorial study referred to, the responses of guayule to temperature and light intensity under high and low nitrogen conditions were investigated. As a matter of completeness some of those results are presented here. Table 8 shows the relative growth rate and rubber content of the plants grown in low nitrogen

Table 8. Ratio, in percent, of guayule plants grown in low nitrogen to those grown in high nitrogen nutrient solutions in full sunlight at two different temperatures.

	Leaves	Stems	Roots	Total
Dry Weight				
75° F.	54	35	52	49
60° F.	43	30	53	43
Rubber Percent				
75° F.		113	80	
60° F.		147	108	
Rubber Grams				
75° F.		38	41	39
60° F.		50	47	53

nutrient solutions to those grown in high nitrogen solutions at two temperatures in full sunlight. Decreasing the nitrogen supply decreased the growth rate in both temperatures by about the same amounts. As would be expected the plants in the low nitrogen solutions had a higher rubber percentage and the increase was greater in the lower temperature. The grams of rubber per plant, however, followed the trend of the dry weights. That is the increase in rubber percentage at low nitrogen levels did not compensate for the decrease in total weight of the plants under these conditions. When the plants were grown in the shade, however (Table 9), the increase in rubber percentage at the low nitrogen level did compensate for the decrease in dry weight. While the results in Table 9 indicate that the rubber content was increased by as much as 80% in low nitrogen solutions the actual percentages were very low--.07% to .13%.

Table 9. Ratio, in percent, of guayule plants grown in low nitrogen to those grown in high nitrogen nutrient solutions in shade at two different temperatures

	Leaves	Stems	Roots	Total
Dry Weight				
75° F.	54	56	61	55
60° F.	52	50	63	52
Rubber Percent				
75° F.		170	143	
60° F.		186	161	
Rubber Grams				
75° F.		100	100	
60° F.		100	100	

Discussion

As a result of the observations and experiments on the responses of guayule to climatic conditions there appear to be some contradictions that need to be resolved. It is generally assumed that any factor which will apply stress to the plant will result in increased rubber percentage and increased rubber yields. However, there are many reports which indicate that there was no increase in rubber when the stress was applied. For example, a drought stress applied between November and March, Table 7c, under optimum temperatures in a greenhouse did not result in an increase in total rubber. However, when the stress was applied in the spring when growth was very active, considerable increases in rubber occurred. In the studies reported on here the maximum amount of rubber per plant occurred in the plants having the highest dry weight regardless of the rubber percentage. While subjecting the plants to drought, low temperatures and low available nitrogen did significantly increase the rubber percentages, these increases in percentage did not compensate for the reduced growth that accompanied the stress as far as rubber per plant was concerned.

Summary

In this paper the requirements of guayule for the climatic conditions of light intensity, temperature and rainfall have been discussed along with some responses of guayule to controlled changes in these conditions.

The results indicated that guayule requires fairly high light intensities to achieve maximum growth and rubber production and that shading or reducing the light intensity by 40% in the Salinas area had a greater effect on rubber production than changes made in temperature and soil moisture.

Guayule is a plant that grows best in relatively high temperatures, 80° to 90° F. It is intolerant of temperatures that average below 60° F. However, the plant grows well and produces the maximum yield of rubber when day temperatures are above 80° but night temperatures drop below the 60° to 70° range. Guayule is sensitive to frost and freezes. It has been known to withstand temperatures as low as 0° but it normally does not produce well where temperatures normally drop below 15°. Frost injury occurs readily if the plants have not received so-called "hardening off" conditions before the frost occurs.

Where irrigation is not available or feasible, the plant grows best in areas where the rainfall lies between 15 and 25 inches per year. Under lower rainfall it does not make sufficient growth to make satisfactory rubber yields. In areas of rainfall higher than 25 inches the shrub tends to have a relatively low rubber content. The shrub will withstand long periods of drought that is several months. Rainfall distribution through the year is almost as important as total precipitation. A high rainfall during the first half of the growing season followed by a dry period of a few months seems to be the optimum conditions for rubber production. There should not be much rainfall during the fall just before the winter temperatures set in, as this makes the plants sensitive to winter kill.

CALIFORNIA INDICATOR PLOTS 1942-43

W.A. Campbell and H.W. Reynolds
Guayule Researchers, Emergency Rubber Project

The guayule rubber production program was launched early in 1942 with a tremendous sense of urgency. The Forest Service was selected as the logical action and operational agency based on a record of crisis-solving efficiency and its resources of trained men and equipment. It also had a general staff geared to emergency situations. It was prepared to draw heavily on the agricultural experience of the Soil Conservation Service and the experience of the Shelterbelt Project in growing plants under difficult climatic conditions. Under the name of the Emergency Rubber Project it took over the secrets, seed and assets of the Intercontinental Rubber Company at Salinas and proceeded to develop large-scale nurseries for the production of the millions of seedlings that would be required for large-scale field plantings.

The Agricultural Research Administration, through the Bureau of Plant Industry, Soils and Agricultural Engineering, was charged with the necessary research responsibilities. The first research task called for the establishment of indicator plots from California to Texas. These plots were designed to test the suitability of different soils, climate, varieties, spacing, and cultural treatments on guayule growth and rubber yields. Many were placed in undeveloped areas and on sites marginal for agricultural purposes to test the feasibility of the then nonproductive areas for farming rubber. Others were located in intensively farmed and irrigated areas in order to test the effects of good agricultural practices on growth and rubber content. At the beginning of the program the planners recognized our basic need for rubber and, if the need became critical, the possibility that good agricultural land would be called upon to produce rubber.

Time was precious and at a premium. Little could be spared for the careful planning that customarily precedes large-scale research operations. The experience of the Intercontinental Rubber Company indicated that successful plantings were difficult to guarantee after March in California. A hurried meeting of the minds in Washington produced the design for one-acre indicator plots wherein two varieties, 406 and 593, would be tested at three spacings and under dry and irrigated conditions. The plots would be scattered from the northern tip of the Sacramento Valley, through the San Joaquin Valley to the dryer areas of south and coastal California. Plot locations would be selected under advice of soils experts and would encompass potentially suitable soils having possibilities for operational or commercial plantings.

Dr. H.W. Reynolds and I arrived at Salinas early in March. We found the weather warm, cloudy and wet. Rainfall had been above average at Salinas and the small nursery that was to provide the necessary planting stock had encountered drainage problems. Many of the seedlings suffered from root rot. We did not know at the time that the nursery was also heavily infected with verticillium wilt.

In order to get the plantings made in the estimated month still remaining in the planting season Reynolds and I divided the state into two parts. Reynolds with Frank Young, a soil scientist, headed north into the Sacramento Valley. I joined forces with John Retzer to work the San Joaquin Valley and further south. John had had experience in this area and was invaluable in plot location. He also joined in the physical labor of actual planting and enjoyed the agony of protesting muscles brought on by our unaccustomed stoop labor.

By the time leases were negotiated, arrangements made for site preparation and plot layouts, time became in short supply. It was necessary to simplify the complicated plot layout which proved too time-consuming on the first trials--and go to a design wherein the two varieties were tested at one spacing. An added reason for simplification stemmed from the seedling supply. Because of root rot, etc., seedlings fell short of all demands making conservation essential.

Survival after one year, for the plots for which I could locate records, ranged from 35 to 85 percent, with an average of 66 percent for 17 plots. This relatively high survival figure for guayule attests to its ability to endure unfavorable conditions and poor conditioning for field planting. The 1942 crop had started to grow in the nursery and was not completely dormant. In addition it has suffered from wet feet. Furthermore the packaging for transportation as practiced by the Intercontinental Rubber Company was geared to colder conditions than we encountered in March and April. Heating took place in some of the boxes and some plots were planted with seedlings whose survival was recognized as problemental. Survival dropped off for a number of reasons: in irrigated plots from too much water during hot weather and the attendant bacterial rot of Phytophthora disease. The seedlings infected by verticillium in the nursery often failed to develop, became stunted or died.

Figure 1 shows the location of 26 indicator plots in relation to nearby towns or cities. Tables 1 and 2 detail the names and designation, soil type, size and date when the planting was completed for those made by Campbell and Reynolds. By the end of April soil moisture and temperatures made survival questionable on the dryer sites. In addition to the 18 plots recorded on the tables, more plots were planted in the Imperial Valley in Southern California and along the edges of the San Joaquin Valley. I have no knowledge or data on these later plantings.

Several samplings for rubber content were made in the summer of 1943. They first experimented with samples bearing leaves. This procedure had its problems so another sampling was made in July of 1943 and the rubber content determined on defoliated shrub. Table 3 presents some data comparing yields of varieties 593 and 406 under dry and irrigated culture. These data were restricted to the 28 x 24 spacing. It shows that greater yields of rubber were obtained after one year on irrigated land; also that rubber percentages were high in some plots under irrigation. While rubber percentages were high in some nonirrigated plots, the rubber yield per acre was low because of the small size of the shrub.

Some conclusions as to the effect of spacing can be found from data from a few selected and comparable plots. This data, in Table 4, presents yield in pounds of rubber per acre. In general, after one year, more rubber was produced from the closer spacings. There are reversals in the trends stemming in part from shrub and rubber content figures derived from plots whose spacings varied because of poor survival. Hence when data from plots compromised by low survival were converted to 100 percent stocking the biological effects of growing space entered the picture.

Later more intensive experiments furnished better data on all the variables supposed to be explored in the indicator plots. Large-scale field plantings were made in some areas where indicator plots had been established which afforded a larger basis for experience in guayule culture than the plots could afford. Spacing and rubber yields were studied in field experiments. Size and rubber yields were often in inverse relation; the larger the shrub, the lower the rubber percentage but the higher the yield per acre. It then became an exercise in economics for the processor and management to determine at what point rubber percentage and yield in terms of shrub tonnage represented the most profitable compromise.

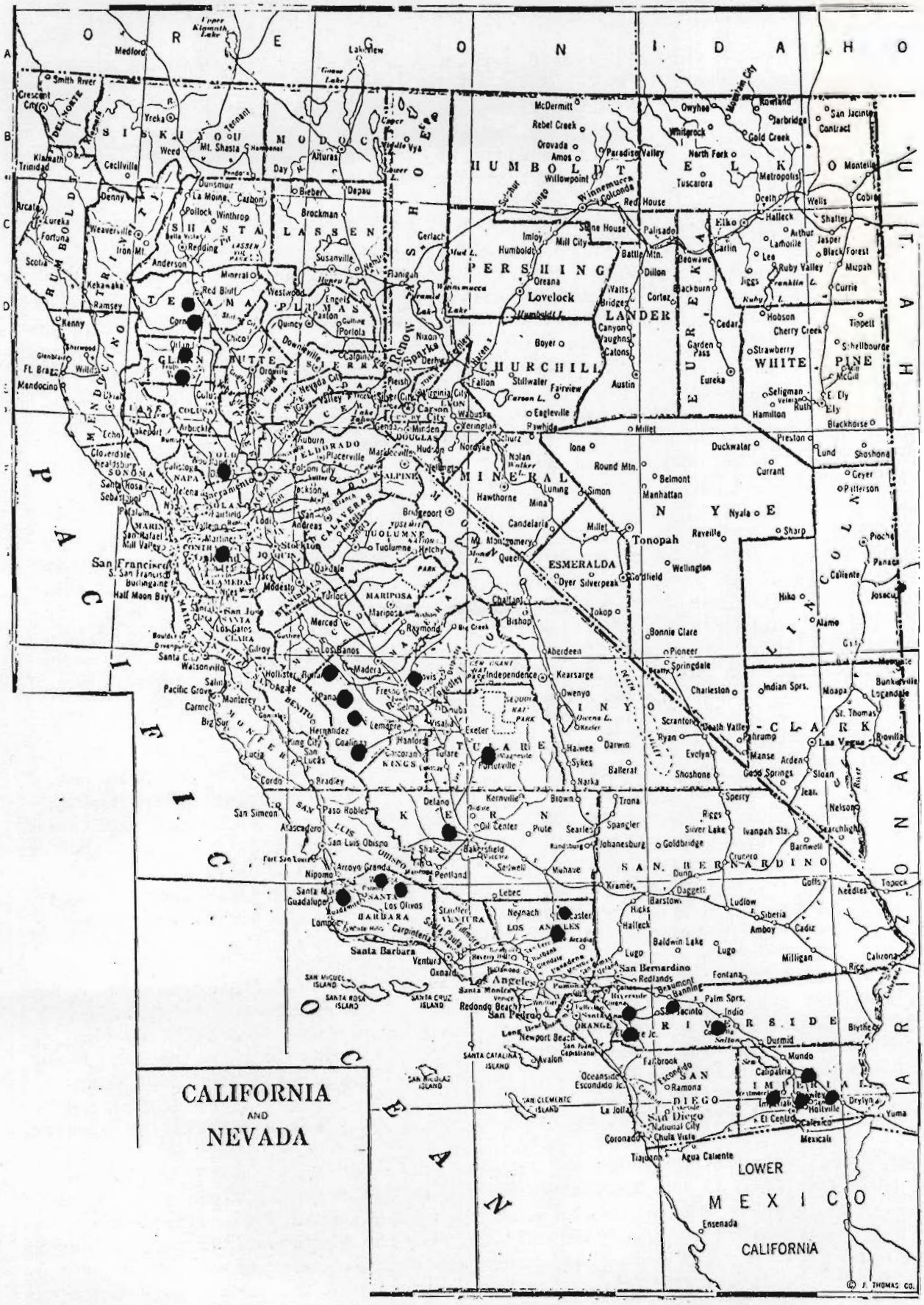

Figure 1. Locations of Indicator Plots in California

Table 1. Guayule Indicator Plots, California (North)[1/]

Nearest Town	County	Size	Soil	Date Finished
		Acres		
Willows	Glenn	1	Silty-clay	3/28/42
Pleasanton	Alameda	1	Fine sandy loam	3/29/42
Willows	Glenn	1	Columbia sandy loam	4/2/42
Davis	Yolo	.25	Yolo silty loam	4/8/42
Willows	Glenn	1	Fine sandy loam	4/9/42
Davis	Yolo	1	Yolo silty-loam	4/25/42
Gerber	Tehama	1	Sandy loam	4/26/42
Gerber	Tehama	1	Silty-loam	4/26/42

[1/]Established by H.W. Reynolds
Row spacing 28" each
Half of plot irrigated except Davis, which was 100% non-irrigated

Table 2. Guayule Indicator Plots, California (South)[1/]

Nearest Town	County	Size	Soil	Date Finished
		Acres		
Coalinga	Fresno	1	Panoche fine sandy loam	3/22/42
Dos Palos	Fresno	1	Panoche silty-clay	3/25/42
Mendota	Fresno	1	Panoche silty-clay	4/1/42
Shafter	Kern	.75	Hesperia sandy loam	3/27/42
Palmdale	Los Angeles	1	Hesperia sandy loam	4/17/42
Little Rock	Los Angeles	1	Cajon fine sandy loam	3/20/42
Banning	Riverside	1	Ramona sandy loam	4/11/42
Hemet	Riverside	1	Sandy loam	4/12/42
Moreno	Riverside	.9	Hesperia fine sandy loam	4/11/42
Garey	Santa Barbara	1	Yolo loam	5/4/42

[1/]Established by W.A. Campbell and John Retzer
All row spacings 28" except Little Rock, 30"
All irrigated except Banning, Hemet and Garey

Table 3. Rubber yields, California plots, sampled July, 1943.[1]

Plot[2]	Dry				Irrigated			
	593 %	593 lbs.	406 %	406 lbs.	593 %	593 lbs.	406 %	406[3] lbs.
Spencer - C-1	1.95	83	2.41	16				
Gerber - C-2	1.05	17	.82	16				
Willows - C-4	3.12	24	2.36	24	3.37	38	2.26	30
Davis - C-9	1.08	19	.84	15	1.24	41	.93	31
Pleasanton - C-15	1.73	47			2.07	63	2.29	82
Salinas - C-50	3.60	61	3.23	80	3.87	101	3.86	105
Dos Palos - C-51					2.50	82	2.28	79
Mendota - C-54					2.27	73	3.42	108
Coalinga - C-60					3.19	139	3.50	153
Shafter - C-63					4.08	212	3.19	166
Little Rock - C-71					3.72	77	3.34	72
Hemet - C-73	4.59	18	4.16	15				
Banning - C-74	3.92	16	3.38	15				
Indio - C-78					2.74	290	2.12	107

[1] After one growing season
[2] Data for 28" x 24" spacing except Little Rock which was 30" x 30"
[3] Varieties

Table 4. Effect of spacing on rubber yields for California plots.

Plot[2]	NONIRRIGATED					
	593[1]			406[1]		
	30" lbs.	24" lbs.	12" lbs.	30" lbs.	24" lbs.	12"[3] lbs.
Spencer - C-1	44	83	63	49	61	142
Pleasanton - C-15	39	47	86			
Salinas - C-49	64	46	100	43	59	87
Salinas - C-50	47	61	102	49	80	97
	IRRIGATED					
Pleasanton - C-15	42	63	115		82	148
Salinas - C-49	60	92	134	134	101	126
Salinas - C-50	61	101	135	86	105	140
Indio - C-78	245	290	261	275	107	214
Coalinga - C-60	112	139	228	103	130	258
Shafter - C-63		212	172	173	166	233

[1] Variety
[2] Rows 28" apart, spacing in row
[3] Yield in pounds rubber from shrub with leaves removed; after one year. Samples taken in July, 1943

Disease losses in indicator plots in California paralleled disease losses in plantations. Irrigation, whether carefully done or not, during high summer temperatures favored several root rots as well as killing from lack of oxygen in puddled areas. On poorly leveled land losses were generally heavy in low places in the field or at the ends of the rows. Verticillium wilt which was present in the Salinas Nursery also occurred in cotton land and in land farmed to other crops. Irrigation or rain, when temperatures were low--that is below 65° F.--reduced the danger from root diseases. Water could be stored in the soil during the winter when temperatures were low and be utilized as the season progressed.

In summary, indicator plots served a purpose. However, the planting program reached its peak of 30,000 acres before evaluations could be had from the plots. All that these plots actually showed was that guayule could be grown with or without irrigation in many areas in California. The cool coastal areas produced the most rubber without irrigation as per the Intercontinental Rubber Company experience. Variations in spacing, survival and cultural conditions made comparisons between plots difficult. In the final analysis all that could be concluded was that guayule would grow and produce rubber from Red Bluff to Indio. The period under observation was too short for meaningful conclusions as to the hazards from infrequent climatic insults at the various locations.

RESULTS FROM THE NEW MEXICO AND TEXAS GUAYULE INDICATOR PLOTS

John T. Presley

The New Mexico Indicator Plots were located at Animas, Deming, Artesia, Loving, Roswell, Las Cruces and Albuquerque. Survival was fairly good where irrigation was available but we soon learned that a post-plant irrigation was necessary in the arid and semiarid Southwest, for establishment. The Animas plot survived for only six months without irrigation. Plots in New Mexico and Texas provided information on the effects of low temperature on guayule. The Roswell plot was severely injured by a 7° F. temperature and the Albuquerque plot did not survive a -2° F. temperature. Considerable loss occurred on the Las Cruces plot from Phytophthora root rot. Guayule is predisposed to Phytophthora root rot by prolonged irrigation application; 24 hours or more appears to provide sufficient time for infection, particularly at the ends of the rows nearest the water outlet. A few wild guayule plants, transplanted from Southwest Texas by Dr. O.F. Cook and Lon Lytton, were still alive at the Las Cruces Field Station when the Emergency Rubber plot was established.

There were 29 indicator plots planted in Texas. I have listed the plots but in the interest of brevity I will not read the different locations. The plots were located on many soil types from Edinburg to Lubbock, thus covering most of the State. Location of Texas plots: Valentine, San Antonio, Lubbock, Ord Gary, El Paso Valley, Pecos (2), Madera Valley, Leon Springs (2), Ft. Stockton, Del Rio, Weyerick, Eagle Pass, Carrizo Springs, Rio Grande City, Kingsville, San Angelo, Candelaria, Casa Peidra, Fawcett #1, Winter Haven, Pecos, Presidio (2), Pearsall, Hebbronville and Linn.

So far as establishment and survival are concerned, our experience in Texas was quite similar to that in New Mexico. The Lubbock plot failed to survive a -5° F. temperature. El Paso, Pecos and Balmorhea plots were injured by cold. At Edinburg the tender leaves of recent transplants were injured by a temperature of 26° F. which lasted for a few hours. Some of the Texas plots failed partially or completely because of insufficient moisture for the transplants to become established. However, both the New Mexico and Texas plots furnished a wealth of valuable information on areas suitable for guayule production as well as on the best procedures to use in establishing the plantings.

Diseases of Guayule

Nursery Diseases: Pythium and Phytophthora root rots, *Sclerotinia sclerotiorum*, *Sclerotinia minor* and Botrytis seedling rots, also verticillium wilt. Some nematode damage.

Transit and Storage: *S. sclerotiorum*, *S. minor* and Botrytis.

Field Diseases: Verticillium wilt, Phymatotrichum root rot, Phytophthora root rot, Diplodia die-back, Sclerotium bataticola, *S. sclerotiorum*, *S. minor*, *Fusarium sp.*, *Rhizoctonia sp.*, and *Sclerotium rolfsii*. An undescribed bacterium has also caused severe losses in several California plantings.

EXPERIMENTS WITH GUAYULE IN ARIZONA

R.H. Hilgeman
Guayule Research, Emergency Rubber Project

Data was obtained from the Progress Report for 1943 and 1944. The major problem was to determine irrigation procedures to reduce loss from *Phytophthora drechsleri* and obtain maximum rubber at least cost.

Tests were made near Glendale, Laveen, Gila Bend, Casa Grande and Gilbert in soils ranging from silt loam (Field cap. 21 to 33%) to fine sandy loam (Field cap. 9%). Water was applied frequently and with a fall stress period by flooding, in furrows and in alternate furrows on each side of a pre-formed bed.

Disease losses ranged from 55% in flooded, frequently irrigated silt loam soil to 1% in alternate rows in fine sandy loam. Almost complete loss occurred in low places where water covered crowns. Perfectly leveled fields are required. All losses occurred between May and October when soil temperatures were above 27° C. at 15 cm depth. Rubber ranged from 5.0% to 7.6% and yield from 139 to 310 lbs/A at one year.

Bi-weekly plant analysis showed rubber was not produced during the growth period between April and September. Most rapid rubber accumulation occurred in November and December and continued through March. Stress in October induced higher rubber percentage.

Irrigation tests in silt loam soil holding 18 acre-inches of water in the upper 8 feet showed irrigations in March and August produced as much rubber as 7 irrigations during the year. About 300 pounds of rubber/acre were produced per

year. The deep-rooted plants removed all available water to a depth of 8 feet. Frequent irrigations increased size of shrub but reduced rubber percentage. Tests in fine sandy loam showed 4 irrigations were required to produce maximum rubber.

Direct seeding on edges of lettuce type beds in March were highly successful. An estimated 400,000 plants per acre were produced in the unthinned rows 14 inches apart and rubber yield was 235 pounds/A at one year. This type of seeding can be done to provide transplants. It may be practical for large direct seeded fields.

Time of transplanting tests with plants grown at Phoenix showed survival as follows: Nov. 10, 12%; Dec. 21, 72%; Feb. 1, 88%; Mar. 14, 54%; Apr. 20, 22%. Storage for 6 weeks reduced survival. Large field transplanting had a high survival of 80 to 88% in January and February plantings.

Comment: (Dr. Uribe Ruiz) The IMIQUIVE (Mexican Institute of Research for Plant Chemical Industries) is applying methods for somatic reproduction of guayule. We have worked nearly two years in the matter. Preliminary results are encouraging especially because old wood cuttings could be used. We reserve for our field of research in the future exploring root grafting and mutations in the guayule plant. The mutations are induced by physical and chemical agents. Both lines of scientific activity are designed mainly for Mexican conditions of accessible hand labor. In IMIQUIVE main activity is concerned with domestication, that is agriculturization of wild plants with economical value.

GENETICS AND PLANT BREEDING

Reed Rollins

Most of the talks have assumed that guayule is guayule is guayule. However, the fact is, this is one of the most complex species of plants that I know about. It is complex in different ways. It is complex because one of the common modes of reproduction is apomixis. This was one of the primary discoveries that we made fairly early. What this means is that all of the introductions and so-called developed strains that were in cultivation, with a few exceptions, have not changed materially from the wild material. During the period of Dr. McCallum's work and selection, over a period of more than 20 years, no fundamental changes had taken place in the material that had been introduced from wild sources. What happened was that he made many trials on many different introductions. These were tested and those that were no good were thrown away. When he found one that was worthwhile he kept it. But he kept trying one introduction after another. Unfortunately, his attempts to improve these by selection were a failure because of apomixis. Practically all of the introductions that were made during the period of the Emergency Guayule Rubber Project similarly remained just like the wild material because they were largely apomictic.

For those of you who do not know what apomixis is, I think I should explain this a little bit. As you know, in the higher plants there is double fertilization and if double fertilization does not occur, in other words if the egg is not fertilized, you do not get genetic segregation and recombination. What happens in guayule is that one-half of the fertilization process takes place, that is to say,

one of the male nuclei fertilizes the polar nuclei in the embryo sac. That gives rise to the endosperm. In these apomictic forms there is no chromosome reduction in the egg cell. The embryo develops from a nonfertilized nucleus. Thus, the inheritance is strictly maternal. It is comparable to taking a cutting off the parent plant and growing that into a new plant. The new plant is exactly like the plant from which the cutting was taken. In guayule this happens via seed, however, which is the reason we term it apomixis. I consider this to be one of the most important discoveries made by the genetics and plant breeding group because for the very first time, it permitted us to begin to do some breeding work. However, this never got off the ground because it took a little while to find this particular fact out. We had first of all to grow our material to a point where we could manipulate it. We carried on a pollination program and we had to grow our plants up to the point where we could see what our progenies were showing us. When we got to that point, it was as plain as the nose on your face that all the varieties then in cultivation were apomictic.

If we were restricted to the use of apomictic plants, this would be a great limitation on any kind of breeding work with guayule. Apomixis poses limitations on crossing between strains; it poses limitations on any selection that might be practical, the development of inbred lines and all this kind of thing. In other words, it could have been a serious obstacle to the usual methodology for improving guayule varieties. However, fortunately it is true that all of guayule is not apomictic. It was also fortunate that in the first series of seed introductions that were brought in during the guayule project, the collections made by Dr. Leroy Powers and others who went to Mexico at that time, included some seed stalks that were completely sexual with normal reproduction. So the possibility of doing the usual type of breeding and ordinary selection was present in this early material. It took us a while to find this out because, first of all, no one suspected that apomixis was the rule and that apomixis was present in the strains that were then in cultivation. The finding of sexual material came about only after tests were made.

The second major discovery that took place was the presence of polyploidy within guayule. This polyploidy turned out to consist of $2\underline{n} = 36$ chromosome populations, populations with $2\underline{n} = 54$ chromosomes and populations with $2\underline{n} = 72$ chromosomes. Individuals were found with $2\underline{n} = 90$ chromosomes and some with 108 chromosomes and even higher polyploidy levels. This is not esoteric information. It provides us with a basis for doing all sorts of breeding manipulations which I will demonstrate to you. One of the important things we discovered was that the 36 chromosome plants were also the sexual plants. So the diploids were the sexuals, the polyploids the apomicts. This information was important because it gave us a handle to go into the field for example and pick polyploids, or apomicts or sexuals. I can do this with a hand lens. I can go into the experimental field or into the wild populations of Mexico and look at the material with a hand lens and predict whether I am looking at a diploid or a polyploid. I will show you why this is so simple. There are correlations between size features of guayule plants and chromosome number. For example, pollen size correlates with the chromosome number. Smaller grains are in the 36 chromosome types, larger grains are present in the higher chromosome types. There is a correlation between the size of the fruit complex and the chromosome number. I should digress at this point, I suppose, and say that what everyone here has been calling seeds are not seeds in the technical sense. They are fruits. Now in common parlance they are called seeds. There is no reason to change that, but technically they are fruits. There is one fruit per flower, and what people call flowers are really inflorescences. What you see on the guayule plant, these little round things, are inflorescences. There is more than one flower in each one of these inflorescences.

In fact, there are five fertile flowers in each inflorescence. The number is greater in some of the other species of Parthenium, however. The number of marginal fertile flowers runs up to as many as 10 in some of the species. But technically, if I refer to it as a fruit complex, what I mean is the little black structure which when thrashed--when the bracts are thrashed off--everybody calls seeds. The fruit complex includes the achene plus the bracts that are present which hang on to it at the time of shedding. So the size of the fruit complex also varies with the chromosome number. We can use that as a key way of finding polyploids and/or apomicts. I am not sure that all polyploids are apomicts. We know that the ones that were introduced and certain ones we worked with were apomicts, but we don't know that there aren't some strains, some wild populations of a high chromosome type in Mexico or Texas that are sexual. There hasn't been enough work done to know. But what I look at to tell whether I'm dealing with a diploid or a polyploid are the trichomes. The trichomes are structures that occur on the leaf surface and they also vary in size, correlated with chromosome number. So there is a very practical value to knowing something about the size of these trichomes and something about their nature. You can simply look at the leaf with a hand lens to see trichomes. If you are used to looking at size relationships, you can predict just from looking at the trichomes whether you are dealing with a 36, 54, 72 or a higher chromosome type. The importance of having a quick and easy way of assessing polyploidy does not show up so much in working with the cultivated materials as it does in looking for particular genetic stalks of different chromosome levels that one may wish to use. Guayule occurs over a wide range, and if a successful program is initiated again it is going to be necessary to go into the field armed with the knowledge we now have and introduce the kinds of germ plasm that we really want to work with--and not leave it to the haphazard way in which it was done in the past.

Another feature that guayule has that seems to occur frequently is haploidy. This is particularly true from the polyploids. Haploidy means that the chromosome number is reduced, say from 72 to 36 in this case. This happens spontaneously. At Stanford where I was working with some of this material after the project closed down, I had a whole row of haploids that had occurred spontaneously in two or three different lines. Now when that happens, the egg has a reduced chromosome number because meiosis has occurred, but the stimulus for apomictic development is still there and the egg in the reduced condition produces a new plant. In this way, there is the possibility of getting segregation in an apomictic line. This is valuable to the breeder because if he has a good line he wants to work with, he can obtain segregation in this way. Then he can cross it back to a polyploid to bring the chromosome number back up again. Thus he will have had some segregation in the families of plants that he was working with providing a basis for selection.

The third important discovery I think we made in our program was that hybridization takes place between guayule and mariola, naturally, and it can also be done in the laboratory. The reason this is important is that it again permits us to assess what is present in the wild and therefore we can pick material that we want for various purposes. There is tremendous introgression of mariola genes into guayule in its natural range. There are whole populations, whole mesa tops, covered with an apomictic form which has in it quite a number of genes that have come from this other common species that occurs throughout the range of guayule. The amount of introgression varies between populations. One reason I say guayule is one of the most complex species I know about is that in the evolutionary history of this species, crosses between mariola and guayule have taken place many, many times at many different places. If one looks at this species in a time span of perhaps hundreds of thousands of years, the present wild populations have been derived from

strains or forms if you wish, of guayule and mariola that have, by evolution, changed to some extent, hybridized, produced particular types which may have spread then changed again over thousands of years producing other types and so on. If one compares, and I've done this in western Texas, the plants on a mesa top, where there may be 150 to 300 acres of guayule shrubs, they nearly all look alike. The plants look as much alike as peas in a pod. Here one sees the end product of a series of evolutionary events. But if you walk down through a valley and on to another mesa top five or six miles away to see another hundred acres of guayule, the plants that are there are usually not quite the same as the ones on this mesa top. They may be very different. And again, you find that practically every plant on that mesa top is alike. They are apomicticly produced. They are as much alike as peas in a pod. So you have ranging over the entire area where guayule occurs this same kind of situation occurring over and over again because of interspecific hybridization and apomixis. We did not get far enough in our studies to really assess this kind of thing to any extent. No one went into the field after we had this knowledge and said, "Okay, let's see how many different forms or different populations of these plants we can accumulate and let's test them out. Let's see what they are good for." Nothing like this was done. For rubber alone we might not want to be interested in genes from mariola because it doesn't have any rubber in it. But if we were interested in extending the range where guayule can grow, we jolly well would be interested in genes out of mariola. Why?

Mariola occurs way up into New Mexico; it occurs as far north as the Grand Canyon of Arizona. It ranges far to the north, far to the east, and far to the south of the natural range of guayule itself. So here are genes available for hardiness that could be easily picked up and moved over into guayule. You might say, "Okay, the rubber content of hybrids between mariola and guayule will be depressed." Maybe this will happen initially but if you know anything about plant breeding and know what the possibilities are, you know very well that this is only a first step. Once you know enough about your material you can hold the hardiness characteristics and then toss in the rubber producing characteristics. By this procedure it should be possible to considerably expand the possibilities of growing guayule in a wider geographic area than is now the case.

If there are problems with the milling of the shrub, there is no reason why the plant breeder can't do something about this if it is known what they are. If leaf drop is important, one can look for the features of leaf drop, and so on.

I mentioned interspecific hybridization as far as mariola is concerned, but one of the really promising kinds of crosses that we made was with *Parthenium stramonium*. This tree-like form grows naturally in Sonora, Mexico. We also crossed guayule with *Parthenium tomentosum* which grows in Oaxaca. These species have very different characteristics than guayule. They grow faster, at least the F_1's grow faster, and I think Dr. Tysdal will have some information on generations beyond the F_1. I stopped with the F_1 because that is where I was when I got out of the work. But the really exciting thing about working with interspecific crosses is that you can literally become a genetic engineer. The two species, *Parthenium stramonium* and *P. tomentosum* have $2n = 36$ chromosomes which are the equivalent of the sexual material of guayule. So you cross the 36 chromosome types of each species, and you get an intermediate hybrid. The F_1 is an intermediate plant, as would be expected when crosses are made between species as is the case within species. But if one takes a 72 chromosome type guayule plant, which is what we did, and crosses it with a plant of *P. stramonium*, 36 chromosomes come from guayule and 18 from *P. stramonium*. The chromosomes of the F_1 add up to 54. You have twice as many chromosomes coming in from guayule as you do from *stramonium*. This produces a hybrid that is not intermediate between the two but it is on the guayule side. It has a lot more genetic material that has been dumped in from the guayule side.

On the other hand, if one takes the 72 chromosome type guayule and uses the occasional plant that shows up in an apomictic line that is sexual without chromosome reduction, you can take 18 chromosomes from the stramonium parent, put it onto the guayule, and produce a hybrid with 90 chromosomes. Seventy-two of those chromosomes are guayule chromosomes and 18 are from the stramonium plant. This gives you an F_1 hybrid that is much closer to guayule than it is to intermediacy between the two species. In one operation, you have done the equivalent of a whole series of backcrosses from an F_1. At the same time, the apomictic feature can be preserved. This means that you don't have to worry about the hybrid fractionating, or being variable. One of the banes of the plant breeder is that whenever you hybridize you've got to stabilize the hybrid product to make possible its being put into cultivation with the requisite amount of uniformity. In the situation described, you have uniformity built in. It is there after that first cross. If you have the right kind of plant possessing the desired qualities, it is ready made. Because of these features, the possibility of chromosome engineering that I speak of in guayule and the other unusual features that I have mentioned, guayule is seen to be a very complex species. It really does have excellent properties from the point of view of the plant breeder.

*I am showing a guayule plant here mainly to get your eyes focused on size, because I want to show on the next slide, for comparison, a plant of mariola, Parthenium incanum. *These are taken at the same scale and you will note quite some differences in size and in the nature of the plant. *I mentioned that one of the quick ways of finding out whether you are dealing with a straight guayule plant or one that is introgressed with mariola is to look at the trichomes. These are some trichomes that have been shaved off the leaf surface. They consist of a cap cell and some stalk cells, usually one or two, that show up here. You will notice that the stalk cells are more or less centrally located beneath this boat-shaped cap cell. *The trichomes of mariola; mariola has a very long, tortuous trichome and if you have ever looked at the surface of the leaf you know that it is sort of cobwebby in appearance. The next slide will show the trichomes of a hybrid between guayule and mariola. The trichomes have some of the characteristics of the cap cell of the guayule type as you can see. They are long and pointed, but the stalk is at one end. In assessing hybridity or introgression in wild plants, it can be done by looking at the cap cell and seeing where the position of this stalk is with regard to the cap cell. This trichome indicates the plant from which it came is about an intermediate hybrid between the two species. *These are trichomes of a plant that is introgressed with mariola, not introgressed very much. It is very close to straight guayule. But if you notice where the stalk cell is, it is down towards the rounded end of the cap cell, and the cap cell itself is quite long and pointed. Using trichomes as indicators is essentially a short-cut technique. You couldn't do this if hybrids had not been experimentally produced and the kinds of cells that are on the leaf surface analyzed. We did that. This kind of information is usable in the field to help with the selection of the kinds of plants one wants to work with. For our friends from Mexico, this could be very important in determining whether a given population is straight guayule or one that is introgressed with mariola. If you have one that is strongly introgressed, the chances are that the percentage of rubber from that population is going to be lower than it will be if you have straight guayule. *This is a map derived from an analysis of specimens of collections of guayule made in Mexico. It includes only the plants that usually would be classed as guayule. Three is essentially the equivalent of an F_1 between guayule and mariola, two is the equivalent of an F_2 from an F_1 backcross to guayule, and one is the equivalent of an F_3 from an F_2 backcrossed to guayule. So the types

*Slides

represented on the map are straight guayule, two grades of introgressed guayule and intermediate hybrid guayule. Here are some things to note. The areas where there is a heavy concentration of introgressed guayule are in northeastern Zacatecas and southeastern Coahuila. But in Durango, there is very little introgression. Only two samples that I had available showed any evidence of hybridization. I have been in Durango since this map was made, particularly west of Mapimi where there are some hybrids and introgressed populations. But this is also the area where $2\underline{n} = 36$ plants are to be found. This is the section where mainly sexual plants occur. The apomicts are common in eastern Zacatecas and in Coahuila. Notice the Big Bend or trans-Pecos area of Texas shows a great deal of introgression. This probably accounts for the fact that the rubber yield from the native shrub of the Texas area was always considered to be somewhat inferior to that of certain parts of Mexico. A careful job of analyzing the wild populations of guayule with regard to how much introgression there is could pay off for anybody who was interested in harvesting the wild shrub. It would also pay off with respect to the picking up of particular plant types that one might be interested in. *I mentioned to you about tossing genomes and chromosomes around and this is literally possible. Mariola, as well as guayule, has a polyploid series. As you see, we made crosses between some of these which were successful. The solid lines indicate successful crosses. These numbers indicate the chromosome numbers that were derived in various ways by crossing various polyploid types. So literally, one can, as I say, engineer the product. Not very much was done in the way of analysis of the hybrids. We had a few of them analyzed for rubber content and the rubber content was depressed compared to straight guayule. I don't think that is terribly important. I think the important thing is that one can cross these species on various levels and can get different combinations of chromosome numbers. It is possible to breed in apomixis or have it already present and hybrids can be recovered that are already to go if they turn out to be all right from an economic point of view.

*The apomicts are, as I said, as alike as peas in a pod. Of these 12 plants in a flat, it doesn't make any difference what you look at, they are I won't say identical, because that's a pretty strong word, but they are as nearly alike as one can conceive. *But apparently something does go on in these apomictic types. We have thought that there must be some autosegregation because every now and then plants not like the others show up. These plants are all the same age, the same family, and these four plants I'd say are very similar, but this one is an off type. The next slide will show several plants. This is the normal type and this is the off type. The ones you can identify as off types are the slow growers. Usually when mutant types show up you are dealing with something that is deleterious, in a direction that turns out to be less good, particularly if you can recognize such plants just by morphological means compared to the normals. What I am calling your attention to here is that if there is such a thing as autosegregation in apomictic guayule, this could be an important genetic procedure to break the constancy of some of the apomictic lines. *Now to show some of the relationships between size and polyploidy. Here we have comparable leaves from three different chromosome plants. The ones on the far right are from a plant with 36 chromosomes, in the middle 54 and on the left 72. The 54 chromosome plant was gotten by crossing the 72 with the 36. The 36 one was a haploid derived from this plant so that we have the mother, the apomictic daughter, and the F_1 between them, with the three different chromosome numbers.

*This is the same sort of correlation between size and chromosome number with different numbers involved. Here is the fruit complex, first face on and then

*Slides

reversed on the right hand side showing the two florets and the bracts. The fertile floret is here, the fruit is inside here. Here is the 36 chromosome type, this is the 72 and this is the 108. Now these are all derived from the same mother plant which was this one. This one is 72. We got the 36 by spontaneous haploidy. We obtained the 108 chromosome plant by selfing the 72 chromosome plant. So this is the fruit complex from the mother, this from a daughter, and this from another daughter, each with a different chromosome number. So, somebody is interested in size of fruits. OK, we can give you a bigger fruit if you need it. It is very easy. *I left the work when hybrids were only at the F_1 level. I think Dr. Tysdal will be able to say something about some later generations of hybrids between these species. *Now, just to show you what I'm talking about when I say you can toss chromosome numbers around. These are all of comparable age. This is Parthenium stramonium, and P. argentatum, guayule, is on the far right. Here are three hybrids that I mentioned earlier with the composition half guayule and half stramonium. This is a 54 chromosome one; it has a 2 to 1 ratio of guayule to stramonium. This is a 90 chromosome one; it has 72 chromosomes of guayule and 18 from stramonium. You can see that these plants go downhill or uphill whichever way you want to read it, in the direction of guayule. *Here you can see the same thing in the leaves which have been taken off mature plants. Upper right stramonium, upper left guayule, lower right the 36 chromosome F_1, 18 chromosomes of each, 54 chromosome type, the 90 chromosome type. The 90 chromosome type which is not very different in leaf form, shape and so on than guayule, is a substantially larger shrub with larger leaf surface, greater photosynthetic capacity, and so on. It is apomictic. There is a lot of fertility in the seeds which could be easily increased.

*Slides

GENETIC AND AGRONOMIC RESEARCH

H.M. Tysdal, Principal Geneticist in the USDA, Retired

I would like to make a comparison, having been brought up on the wheat plains of western Canada. We grew a variety called Bluestem wheat, and many years it was so infected with red rust that the yields were almost nil. When driving through with the binder the cloud of red spores was so thick I could hardly see the team! If we now used this variety we could not produce enough wheat for ourselves, but by the miracle of plant breeding we have overcome the rust problem as well as others. We can not only produce enough wheat for ourselves but also for millions beyond our shores. Similar plant breeding miracles have been produced with corn, with soybeans, and probably most any crop you wish to mention.

This is not true of guayule--we are still in the Blue stem stage or worse. There has never been a continuing, fruitful breeding program in guayule. To be sure, Dr. McCallum had as many as 1300 selections but the nature of reproduction was not known. With all his other duties and the discontinuation of his program, he could not follow through with them. The story of the other breeding programs on guayule are all too well known. They were chopped off!

To give you some idea of the possibilities of a breeding program, I would like to give you two examples of progress. Dr. Powers and Dr. Rollins have provided a beautiful foundation of knowledge, particularly with regard to reproduction (including apomixes) for the furtherance of a plant breeding program.

The first example includes the use of interspecific hybrids. As Dr. Rollins has pointed out, guayule can be successfully crossed with such tremendously different species as P. stramonium which can easily grow 10 to 15 feet in height in a few years. Such crosses were made by Dr. Rollins and by us. The F_1 is very vigorous but has no rubber. However, we were able to carry some of these crosses into the F_2 and many segregates continued to be vigorous and contained a higher percentage of rubber than the F_1. It was impossible to carry this program forward because of the discontinuance of the project. However, it seems very feasible and probable that one or more back crosses to guayule would produce a much more vigorous plant with high rubber content, thus enabling the production of harvestable shrub in a shorter period of time, or a larger yield per acre.

In this connection the importance of collection of seed of various native shrubs in Mexico to use in a breeding program should not be overlooked. This has been done by Dr. Powers and Dr. Hammond, but further collections should be made.

The second example of progress is that of hybridization between different strains of guayule. The tracing of the parentage of a strain which was the highest rubber yielding in a two-year test at Shafter, California, a warmer area than Salinas, will illustrate. Selection #11635 produced 71.3 grams of rubber per plant compared to a yield of 30.2 grams per plant from the standard variety 593, grown in the same test. (See Hammond and Polhamus, Bulletin #1327) These plants were approximately equal in size so this yield per plant is indicative of yield per acre. An even more striking result is the fact that high rubber content was possible under these very warm conditions where the standard variety 593 does not perform so well.

The above cross, #11635 was a controlled cross made in our program between a 54-chromosome 4265-I plant and a plant of the 36-chromosome selection N 264. The 4265-I plant came from a selection made by C.A. Taylor and H.M. Benedict from a collection made by Dr. Powers in 1942 from Durango, Mexico. The selection N 264

was made by selecting within a sexual strain. Cross #11635 followed the pattern expected in this unusual plant, viz the fertilization by an 18-chromosome gamete from the 36-chromosome sexual selection with an unreduced 54-chromosome gamete from 4265-I producing a 72-chromosome apomictic strain which #11635 proved to be. This open-pollinated selection produced only one off-type plant in a population of 648 plants, indicating an extremely high degree of apomixis. Thus the variety was fixed without further work; a plant breeder's dream.

In conclusion I would like to say that in my opinion breeding and improvement is essential as a first requisite for the successful commercial growing of guayule. This could be done with an adequate breeding program.

Comments

In reply to Lobenstein's remark showing concern about rubber per acre, Tysdal replied, "The yield per plant reported is indicative of the possibilities of yield per acre because the difference in rubber per plant is related more closely to the percentage of rubber in the plant rather than the size of the plant. I agree that the yield per acre is the objective."

PLANT BREEDING

G.P. Hanson
Los Angeles Arboretum

Since I am under 50 I ought to explain my relationship to guayule since I obviously could not have been involved in the project at the time that most of you were. Two years ago, Hugh Anderson came to the Los Angeles State and County Arboretum and asked if we would consider getting involved in a breeding program. At that time we didn't know very much about guayule; so my first step was to go into the literature and find out what had been done; then to analyze the results and see whether or not it seemed to us if this was a feasible thing to do.

As some of you know, we did produce a proposal listing what we thought could be done with guayule. It seemed to us that it would be a good time to conduct the study; we listed some of the prospects for a favorable result, how we would proceed, and an estimate of costs for the breeding program. We have written this and some of you have seen it. Now we are quite optimistic about the potential of guayule, especially if a breeding program is instituted. Dr. Rollins and others have emphasized this.

One of the things I would like to do is tie together the things that have been said here. Joel Schechter noted that in their feasibility study it was necessary to get an annual yield of 800 pounds of rubber per acre per year. Dr. Bonner said that at the time of the termination of the project they were getting about 750 pounds of rubber per acre per year. That's pretty close. If we just start back 25 years ago, and of course we are using the same genetic materials, we ought to be able to get that. As Dr. Rollins has suggested, with a breeding program we can go much more beyond that. The varieties which were being used (593 primarily) had undergone very little selection in breeding.

In the 40's when guayule was being studied and being grown commercially, its production of rubber was just slightly less than that of Hevea. Dr. Bonner noted that at the present time the average yield in Malaysia is 1200 pounds per acre. If we include the best producers, it's 2000 pounds per acre and he even suggests that if we add the ethylene it's up to 6000 pounds per acre with a potential of 9000 pounds per acre per year. Using the same rationale he used to predict this 9000 pounds, we ought to be able to get the same potential with guayule. We have a big advantage with guayule that they didn't have with Hevea. The rubber tree has a very long generation time of seven years whereas guayule has a generation time of less than a year--so we can proceed more than seven times as fast. The plant breeder is concerned with the generation time as to how fast he can proceed. If the Hevea people in 25 years have gone from 800 pounds per acre to 4000 pounds, why can't the guayule people do that in a much shorter time?

What is possible now? We have various sources of seed, one of which is the National Seed Storage Laboratory at Fort Collins, Colorado. Unfortunately, they have very small quantities of seed. Hugh Anderson has seed available; Joel Schechter has seed available from his studies in Israel and of course any breeding program is going to eventually have to go back to the wild stands as Dr. Rollins has mentioned. As far as the breeding methods which we would be involved in, standard breeding techniques would be used, at least initially, to select for a high economic yield. We are concerned about pounds of rubber per unit area, per acre, but we also are concerned about percentage rubber because those that have to do the milling would much rather have 700 pounds per acre with not much shrub than 700 pounds per acre with a lot of shrub. There is a trade-off there that has to

be considered. We'd be breeding for those factors which contribute to a high economic yield with the desire being the lowest amount of shrub, unless the pulp becomes more worthwhile than does the rubber. So one would be looking at various criteria and would be selecting not just one plant but a large number of plants in the population. It is entirely possible that if we're dealing with a segregating population now, or a large number of individuals, many plants might yield the same amount of rubber but for different reasons. Some of them might have a large amount of leaf surface, enough that can produce a large amount of rubber, but have a relatively large trunk and not much branching. Others have a lot of branching. I think there's been a fair amount of research done showing that the more highly branched the shrub is, the more rubber there is; thus one would select for that. Another plant might have a high amount of rubber simply because it is more disease tolerant than another one. These are various things that I think one would have to select for and it would take a number of generations to come up with what we're looking for.

Dr. Rollins has noted a number of cytogenetic techniques which really were not used in developing the new varieties but certainly we should use. This includes bringing in the other species and trying to increase the range of guayule to adapt it to new environments or environments beyond which it now grows. Another technique which Dr. Rollins did not mention but which certainly is a continuation of what he has talked about is the use of aneuploids. Instead of dealing with entire chromosome sets, one would introduce only one or two or three chromosomes from mariola or from P. stramonium. Techniques have developed since the time of the Emergency Rubber Project by which this can be done; in fact, these things are being done now in the commercial breeding of wheat and cotton.

I would like to say a couple of things about related research kinds of things which are possible and are necessary. Someone mentioned that it is necessary to have irrigation, if possible, otherwise don't try to grow guayule. He's saying this because it has to have water at the time of transplanting. Since the Emergency Rubber Project, techniques have been developed whereby one can actually put the plant in the ground and water it with the same machine. In other words, in this case you have the plant growing in the soil; you're putting down pot and all. This is, I understand, what is being done commercially with tomatoes in certain areas. Maybe this is expensive but it certainly is a possibility for growing guayule where irrigation is impossible. If the seedling is started at the right time it may become established.

We need to look at the possibility of experimentally controlling apomixis. This, of course, is the kind of thing that the breeder must look at. Can he control apomixis experimentally to get around some of the problems? People are going to start getting involved in research programs and we are going to compare notes. We already know that there are two groups involved in a research program, the Israeli people and the people from Mexico. We need to standardize a method by which we can communicate with each other. I understand that people in Mexico are using a chemical extraction method of analyzing rubber and we know from the previous studies that have been done that the chemical methods of extraction are not necessarily comparable to the physical methods. The people who are going to do the work need to get together and decide which methods to use or how we can compare them. The plant breeders are optimists. It also seems to me that this is a good time to continue with guayule but we need to go at it from a plant breeding program as well as these other things. If it is now possible to proceed using standard varieties, think how much better it would be after the plant breeders had a few generations of work.

MARKET POTENTIAL AND ECONOMIC PRODUCTION

R.M. Pierson
The Goodyear Tire and Rubber Company Research Division

Dr. Vietmeyer felt that he had to have at least one person who knew as little as possible about guayule beforehand. I think that's why I'm here--to look at it from the viewpoint of potential consumers. As a matter of fact, having not been here the first two days, I think I can safely say I'm the most nonexpert here and thus proclaim myself.

I'll be talking first about the world-wide rubber usage picture, dividing it somewhat between natural and synthetic and then the various types of products into which it goes; then a section on what properties of natural rubber are especially important in maintaining its market, no matter how cheap synthetic might become. In other words, what are those most critical properties of NR which we hope will be attained in guayule and which we in the synthetic natural rubber field have been likewise attempting to achieve? Then I'll be talking about the analytical information we've gotten recently on the two samples of guayule sent us, and finally some concluding remarks on what might seem to be obvious inferences on the possible directions which a renaissance of the guayule program, if undertaken, might go.

Launching first into the statistical side, Figure 1 shows the total world use of rubber for 1963 and 1973, broken down by the principal sectors and adding up to somewhat over 10 million tons a year by 1973. While it isn't necessary to belabor how these break down, I think a very significant point to keep in mind is that the proportion represented by the U.S.A. is much nearer the saturation point for obvious reasons. In fact, it's getting to be a little over-saturated now. As the impending motorization of the developing areas of the world quickens its pace, the proportion outside the U.S. will really begin to skyrocket. Where has the natural rubber gone in a generation or so since synthetic rubber production reached a point where nearly satisfying demand?

Figure 2 shows what has happened to natural rubber in percentage terms in approximately a generation. In looking at that curve, it might give pause to someone contemplating coming in with a new competitor for natural rubber--it may not be the best star to hitch one's wagon to. But it is very deceptive (Figure 3) because in that same time the total amount of rubber has increased very dramatically; actually in an absolute sense the natural rubber usage has just about trebled. The reason is that it is simply keeping pace with expansion of auto tire production. The use of truck tires is also growing even more rapidly. Over the long haul this is going to increase at a great rate so the future for any natural rubber competitor--whether synthetic or an alternative natural source--is going to be a very good one.

What about the price? Figure 4 shows the period from 1972-75 up to current. As you can see, it has undergone very wide fluctuations. The reasons for the unusual numbers in the ordinate here is that this is a paste-over of the Singapore prices. During this roughly four-year period, there has been only one relatively short period of relatively stable prices, and as is so true over the years with natural rubber, it has undergone an almost threefold fluctuation, rather typical of many commodities. During this same period of time, the various versions of synthetic natural that have come on the market have enjoyed about a three- or four-cent premium, primarily because of their greater uniformity over most of that history and their greater ease of breakdown. However, that differential is beginning

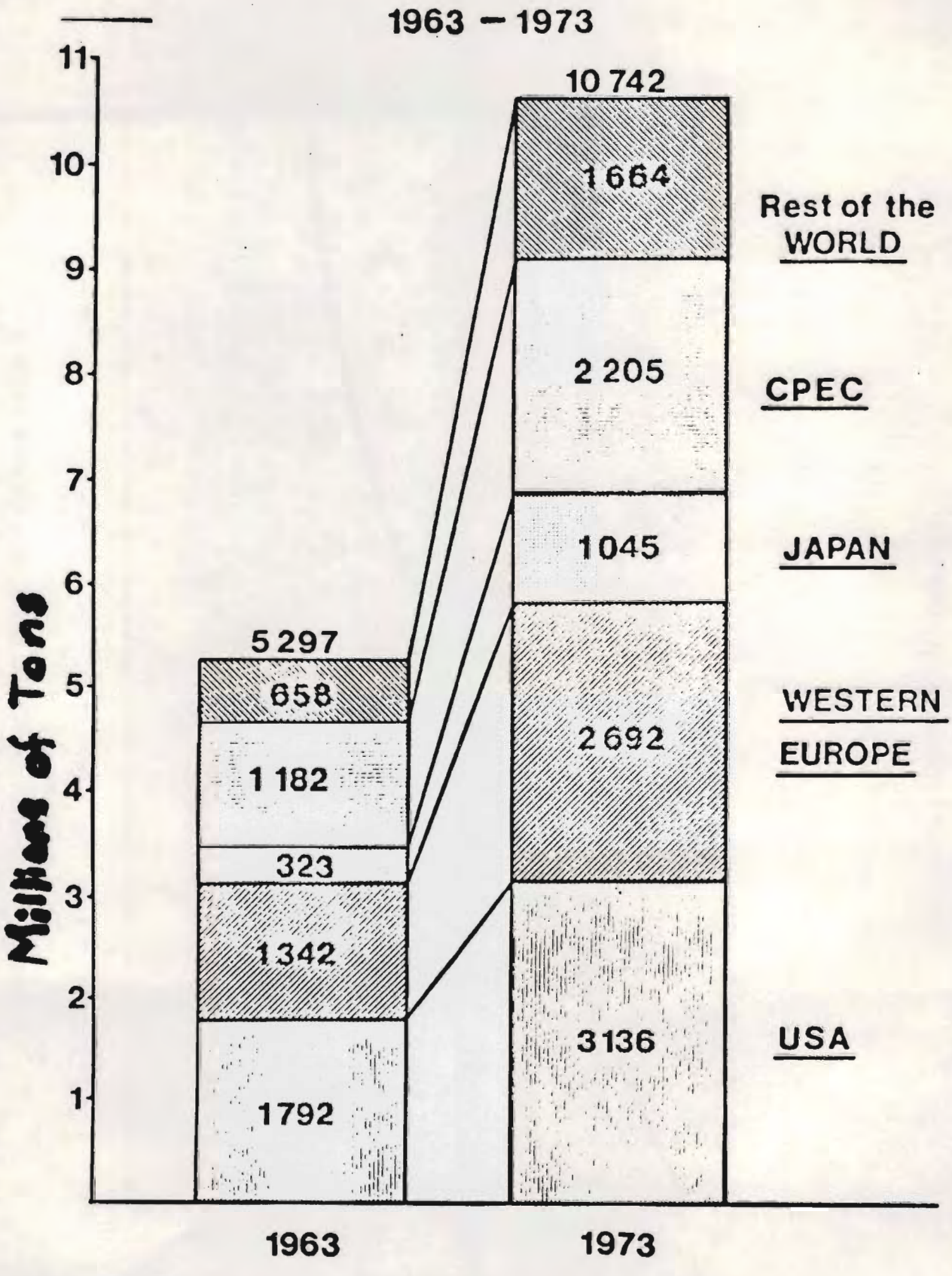

Figure 1. World Rubber Usage

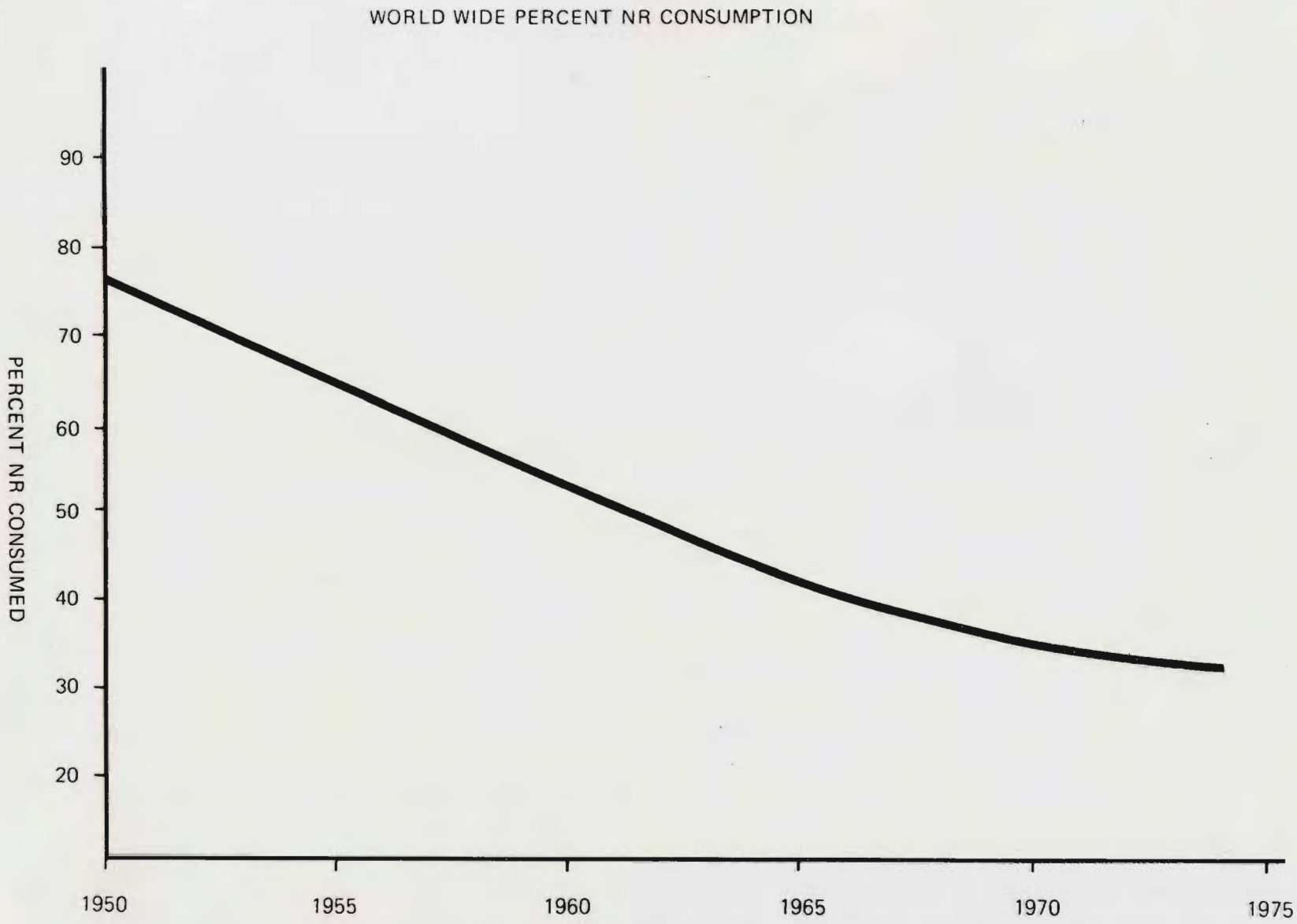

Figure 2. Natural Rubber Consumption as a Percent of Total World Rubber Consumption

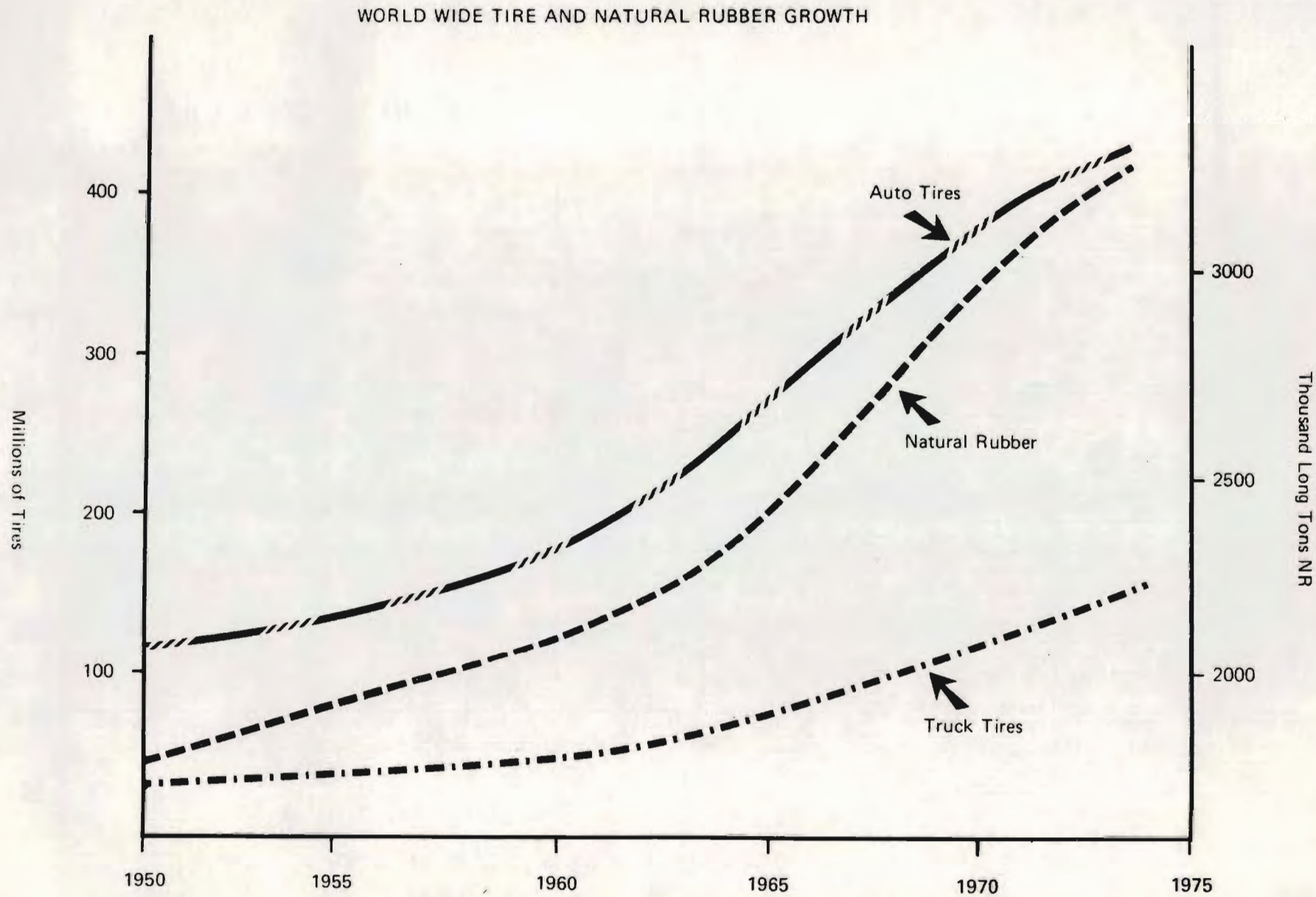

Figure 3. Growth of Tire Markets vs. Natural Rubber

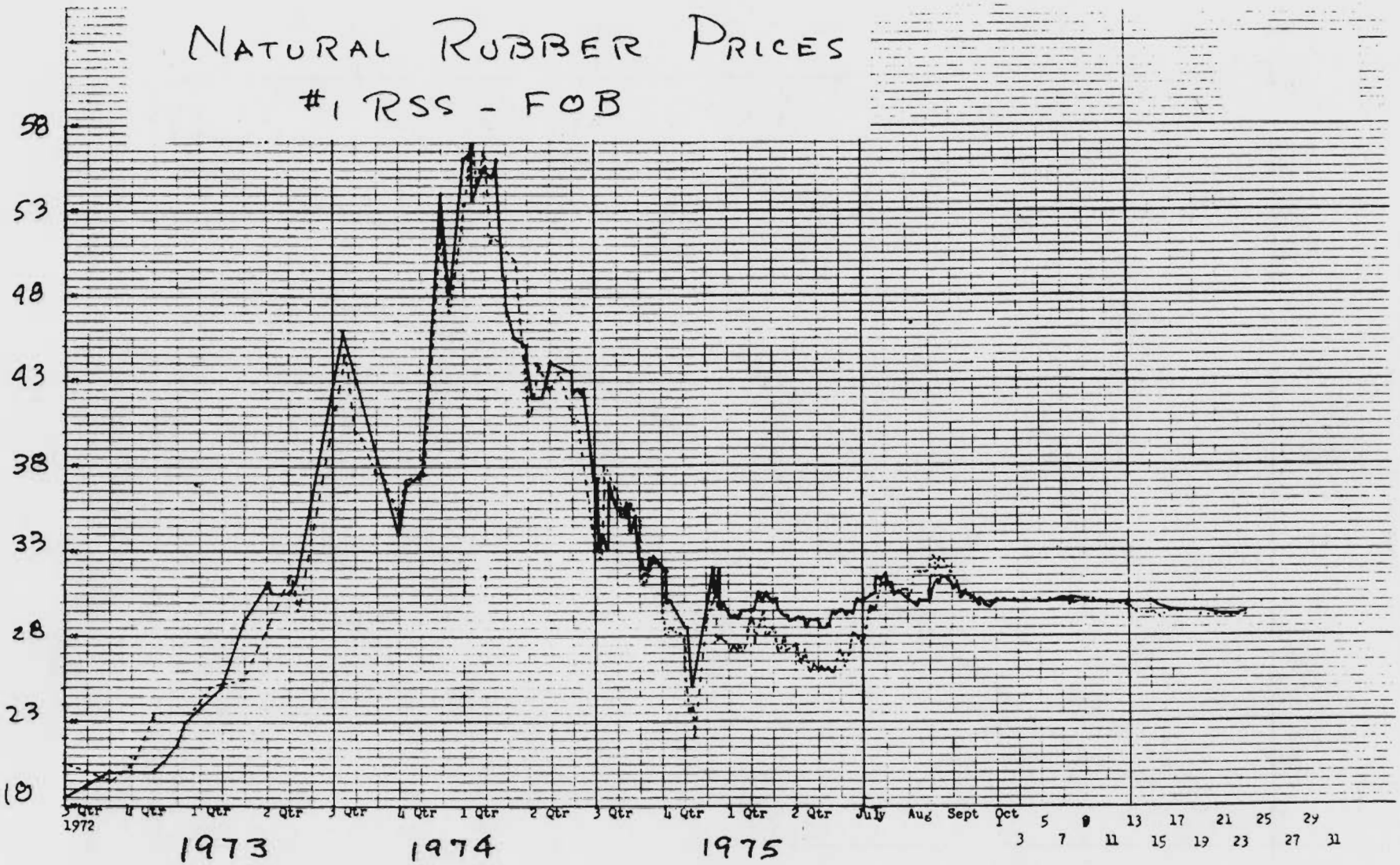

Figure 4. Natural Rubber Prices

to disappear. SBR, the styrene-butadiene rubber that is the workhorse of the industry, has been at about an average of 22-24 cents; it's currently 25-1/2 cents.

What are the principal uses of natural rubber? Figure 5 shows the U.S.A. natural rubber consumption, which unfortunately is not documented through the government agencies. However, this presents somewhat of an estimate. As you can see, the greatest percentage by far goes into tires, followed by the broad range of industrial products, primarily certain large conveyor belts and hose. No other single product area accounts for more than five percent. Looking at tires specifically (Figure 6): In the U.S.A. and Western Europe, the U.S. percentage of natural rubber in the tire is traditionally--and has been for a long period of time--appreciably less than that of Western Europe, the sole exception being aircraft tires which in both cases are practically all natural rubber. Truck and bus tires, which poundage-wise account for those high percentages of natural rubber, are the principal area where natural rubber properties are most important in maintaining its assured use in the future.

Figure 7 represents a major shift in consumer preference in the U.S. (following one which has already occurred in Western Europe) away from the old standard bias tire starting only as recently as three years ago. The bias belt itself had been on the market for only two or three years at that time. As radials have come into the picture, they have already more than overtaken both of the other principal types. This greatly complicates the picture from the standpoint of the tire producers because it seems more apparent now than had been originally thought--when radials first came in--that all three will remain with us for a long time, rather than radials displacing one or both of the other types. What does this translate into in terms of projected uses for radial tires over the longer haul? Beginning with this very low base in original equipment--that is, the tires shipped to Detroit--combined with replacements for a very low three percent total, growing to more than 12 times that amount in five years and getting well beyond the 50 percent point in another five years. (see Figure 8)

Looking at just a typical automotive tire (Figure 9) you can see that the amount of synthetic is approximately 85 percent of the total in the bias belted, but the NR required is almost doubled as one goes to the radial tire. In looking at truck tires, Figure 10 shows the comparison between the bias ply and the radial. The radial shows an even greater requirement of natural rubber so that as the radial tire becomes a more and more predominant factor in U.S. tire usage, its role in determining whether either natural or something which is a full equivalent is used will become greater and greater.

An important factor in the decision as to what type of guayule will become most accepted in the future is the most important properties in the guayule which will assure its becoming a replacement for natural rubber. This is essentially the process which the "synthetic natural" rubbers had to go through over a period of roughly a decade. Figure 11 shows a relatively early comparison of natural rubber with the two principal types of synthetic natural: one, the so-called Zieglertitanium type, the other, the lithium type--the latter was espoused especially by Firestone and Shell--but in recent years have faded from the scene. Let us look particularly at the third column which has to do with the microstructural purity. These figures are somewhat superseded by improvements in the method of measurement as NMR come into the picture, along with greater refinements in the measurement of infrared. In at least a relative sense they show that this

RUBBER PRODUCTS	PERCENT
TIRES	72.2
INDUSTRIAL PRODUCTS	9.6
CARPETS	4.9
FOAM/SPONGE	4.0
SHOE PRODUCTS	2.4
ALL OTHER	4.1

TOTAL = 654×10^6 KG

Figure 5. 1972 Uses of Natural Rubber in U.S.A.

	% NR	
	USA	EEC
AUTOMOTIVE	13	22
TRUCK/BUS	55	75
TRACTOR	30	60
BIKE-MOTORCYCLE	10	30
AIRCRAFT	90	90
RETREAD	12	33
TUBES	5	5

Figure 6. Estimated NR Use in Various Types of Tires - 1970

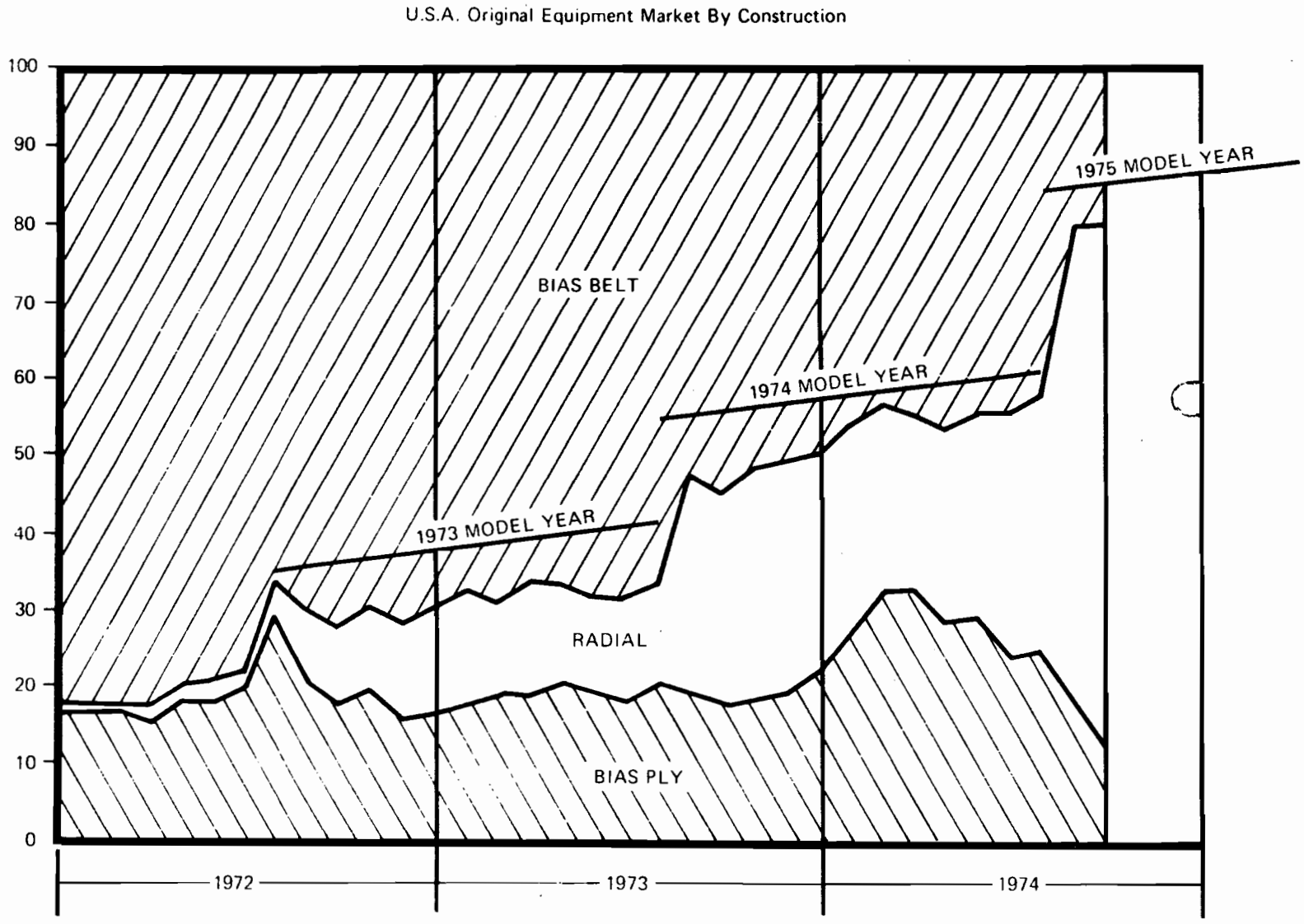

Figure 7. Expansion of Radial Tires Delivered to Automobile Manufacturers

PERCENT RADIAL TIRES U.S.A. AUTO MARKET

	Percent Original Equipment	Percent Replacement	Percent Total Market
1970	1.2	3.5	3.0
1975	60.0	30.0	38.0
1980	85.0	46.0	56.0

Fig. 8. Projected Growth of Radial Auto Tire in U.S.A.

TYPICAL AUTOMOBILE TIRE USAGE

(ALL H78-15 SIZE)

	BIAS PLY	BIAS/BELTED	STEEL BELT RADIAL
SYNTHETIC	5.37 KG	5.36 KG	5.09 KG
NATURAL RUBBER	0.90 KG	0.86 KG	1.71 KG
NR INCREASE	-	-	99%

Figure 9. Typical Automobile Tire Usage

TYPICAL TRUCK TIRE USAGE

(10:00-20 SIZE)

	SUPER HIGH MILER[a] BIAS PLY	UNISTEEL R-1[b] ALL STEEL RADIAL
SYNTHETIC	15.55 KG	9.09 KG
NATURAL RUBBER	5.76 KG	15.17 KG
NR INCREASE	-	163%

[a] SYNTHETIC TREAD
[b] PREDOMINANTLY SYNTHETIC TREAD

Figure 10. Typical Truck Tire Usage

NATURAL RUBBER VS. SYNTHETIC POLYISOPRENE

Polymer	Mw	Structure	Crystal	Feature
Natural	High	98 Cis 1,4	High	Excellent Unvulcanized Strength Good Hot Tensile Good Hot Tear
Synthetic AL/Ti Type	High	97 Cis 1,4	Mod	Fair Unvulcanized Strength Good Hot Tensile Fair Hot Tear
Synthetic Li Type	Very High	90 Cis 1,4	Low	Poor Unvulcanized Strength Poor Hot Tensile

Figure 11. Comparison of Natural Rubber versus Types of Synthetic Polyisoprene

modest, but quite important, difference of approximately a percent or so between the aluminum type and natural is reflected in performance in a very perceptible difference between what we refer to as unvulcanized strength--more recently renamed "green strength"--and in hot tear. In the case of the lithium type which is substantially lower in microstructural purity--and this is the primary reason why this category of synthetic natural rubber lost out--the green strength and the hot tensile were even poorer.

Figure 12 is simply an enumeration of the principal physical property measurements which can be run in a moderately well-equipped rubber laboratory, showing that in the usual things--that is, tensile and so forth--synthetic polyisoprene, at least the higher Cis contents, can look to be almost equivalent of NR. Many people, including many close to the rubber industry, are unaware that practically all the commonly used tire compounds--and there are literally hundreds of them--have evolved into blends of not only NR and synthetic natural rubber, but various other types of synthetics. The blends serve the purpose of bringing out the qualities of each that most serve the combined needs of processability, fabricability and performance on the one hand, and of being able to shift into alternative formulations as price and availability picture change with time. Thus, the tire producers are never really locked into a single formulation. This is just a representative tread compound whose performance particularly requires wear resistance and groove crack resistance and traction (Figure 13). Such criteria are playing a bigger role as DOT regulations come into the picture more and more, and Figure 13 shows that a typical tread compound really requires no polyisoprene at all--and is predominately SBR with some of the solution type of polybutadiene as included. The carcass compound (Figure 14) requires especially high cord adhesion, fatigue resistance, and heat durability (meaning not so much heat aging but of the ability to retain good physical properties during the many, many hundreds of hours that the tire is run at temperatures as high as 150° C.). This is where polyisoprene really comes into its own, so such tires, at least in the carcasses of the larger tires, still are predominantly polyisoprene. I'll come back to this a little bit more.

Figures 15 and 16 show those areas where natural rubber's performance really resists encroachment and probably will do so for at least the immediately foreseeable future. Even the most ambitious attempts to make a true duplicate encounters problems in airplane tires which, as previously brought out, are still essentially all natural rubber; truck and bus tires in the carcasses; and in the large conveyor belts; and certain types of hose.

I want to get into the subject of green strength (Figure 17). Green strength is a rather crude definition of a number of not easily quantitatable parameters that essentially define the ease of fabrication of a tire during the process of converting it from the uncured but totally assembled barrel-shaped form in which all tires are made; that is, the ability of that assembly to be deformed into the final torus shape of the tire without losing contact between the various portions. In other words, it is a combination of measure of strength and ease of flow and capability of hot forming. The easiest way to get at least a semi-quantitative measure is to make tensile-type measurements on uncured, compounded stocks. What one sees is that the synthetic naturals can follow natural rubber up to a yield point, but the difference (Figure 18) is manifested at the higher elongations; the higher the temperature at which such measurements are made, the greater these differences are, so that the parameter "green strength" is going to play an even greater and greater role as the use of radial tires grows because the requirement of having good green strength is much greater in the radial type tire.

PROPERTIES OF CIS 1,4-POLYISOPRENE BLACK (25 HAF) VULCANIZATES

	POLYISOPRENE	HEVEA
TENSILE, PSI	4100	4200
ELONGATION	700	630
MODULUS AT 300%, PSI	680	990
HOT TENSILE, PSI	2950	3000
COLD REBOUND	84.5	83.4
HOT REBOUND	88.9	88.4
DYNAMIC MODULUS	44	46
INTERNAL FRICTION	5.3	6.2
DYNAMIC RESILIENCE	74	72
HEAT RISE, H_x	29	34
HEAT RISE, H_f	71	71

Figure 12. Properties of Cis 1,4-Polyisoprene Black (25 HAF) Vulcanizates

TREAD COMPOUND

REQUIREMENTS
- WEAR RESISTANCE
- GROOVE CRACK RESISTANCE
- TRACTION

COMPOUND

SBR	75
POLY BD	25
OIL	40
CARBON BLACK	75

Figure 13. Tread Compound

CARCASS COMPOUND

REQUIREMENTS —
- CORD ADHESION
- FATIGUE RESISTANCE
- HEAT DURABILITY

COMPOUND —

POLYISOPRENE	50
COLD SBR	25
POLY BD	25
CARBON BLACK	40

Figure 14. Carcass Compound

AIRPLANE TIRES

TRUCK AND BUS TIRES--ESPECIALLY IN CARCASS

LARGE CONVEYOR BELTS

CERTAIN TYPES OF HOSE

Figure 15. Principal Use Areas Where Natural Rubber's Performance Resists Encroachment by Synthetic Rubber

GREEN STRENGTH--ESPECIALLY RADIAL TIRES

HOT TENSILE

HOT TEAR

AGED HOT TENSILE AND HOT TEAR

Figure 16. Key Performance Properties in Which NR Remains Pre-Eminent in Truck Tires

WHAT IS IT?

WHY IS IT NECESSARY?

NR VERSUS SYNTHETIC NATURAL RUBBERS

GROWING IMPORTANCE IN TIRE FABRICATION

Figure 17. Green Strength

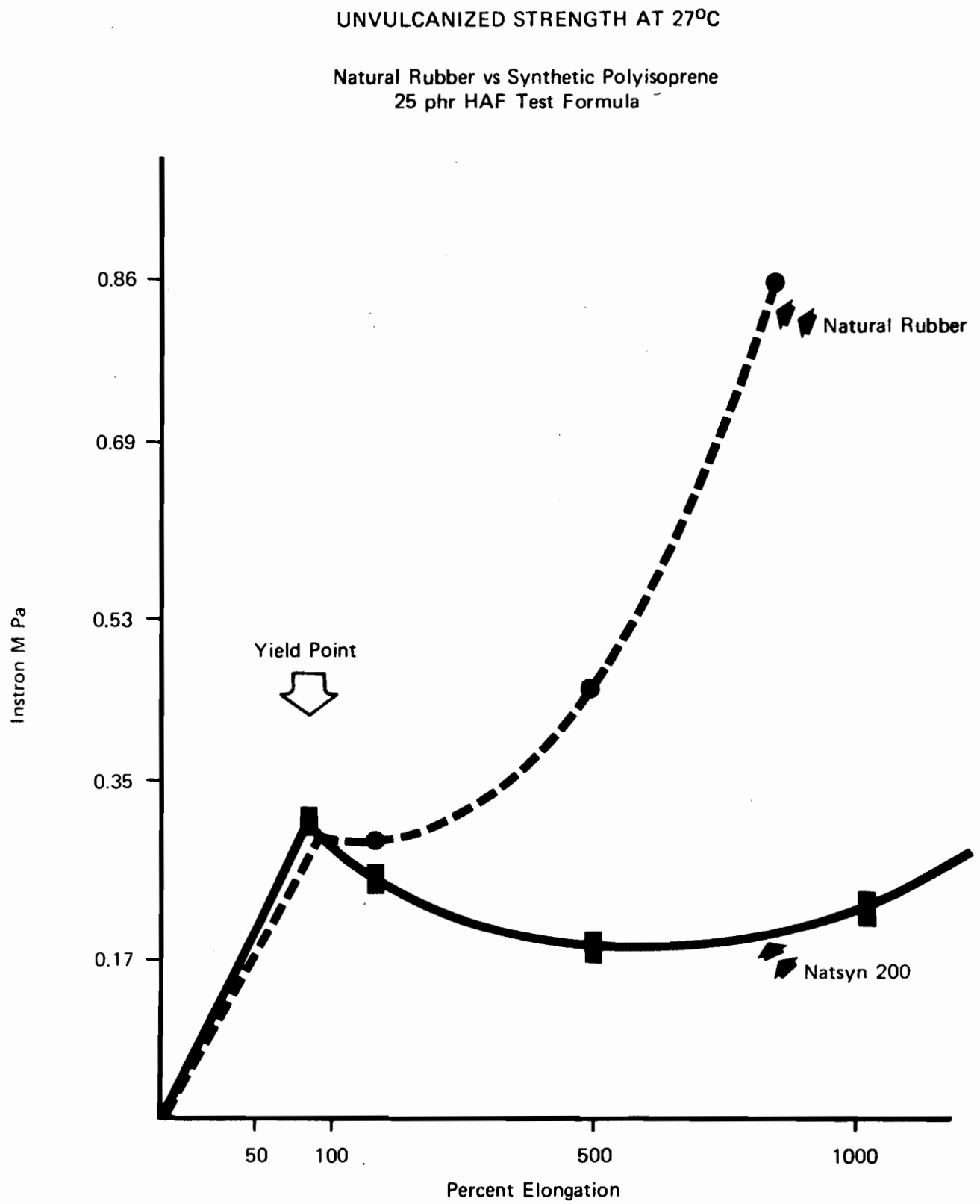

Figure 18. Unvulcanized Strength of Natural Rubber vs. Natsyn 200 Polyisoprene

Looking at one specific area of a particular type of tire, namely a radial truck tire (Figure 19) where this requirement does show up often is down in the bead area. In the case of a high green strength it retains its designed shape, having gone from the original barrel to the torus shape, and all these parts hang together. When green strength is insufficient, there is a coming apart and usually a defect which requires rejecting the entire tire simply because they cannot be mended.

I want now to get into the subject of the analytical data that we've gotten just recently on the two samples of guayule, one a 1945 Bakersfield underesinated sample which we purified, and the other from the bale that Noel Vietmeyer referred to. Figure 20 shows an NMR scan. Within detectable limits, the microstructure is within a half percent of Hevea. The purity in Cis-1,4 content was confirmed by infrared. The NMR was measured, incidentally, with a 60 megahertz Varian instrument; we had access to a 300 megahertz instrument too and it showed the same thing. We felt with great confidence that the earlier data measured in the 30's and 40's on x-ray patterns was very much confirmed by the best techniques we have now for determining very small amounts of inhomogeneities in microstructure.

Looking at a very sensitive physical measure, DTA, and comparing guayule with pale crepe, this is the purified form of guayule (Figure 21). The glass transition temperature (the sharp break here) is at the same temperature for both polymers. It's not terribly significant because all polyisoprenes that are in a Cis configuration would show about the same break point. However, when one cold soaks the rubber for a long period of time, in this case two days at -20° C., one picks up the high degree of crystallization which can only occur in a quite high microstructural purity (Figure 22). The pale crepes and the two samples of guayule were so nearly like each other we have considerable confidence that the requirements of carcass compounds could probably be met with guayule, providing molecular weight and the other less easily detected parameters were also the same.

We ran some GPC chromatograms on the 1945 sample (Figure 23) and, while these elution curves may not be terribly meaningful to those of us who are not working with GPC every day, the calculated molecular weights therefrom do show that both the purified underesinated 1945 sample and the 1953 deresinated has a very respectable number average molecular weights. This, of course, is unmilled (Figure 24). How do these values compare? Unmilled pale crepe is considerably higher than the figures shown but natural rubber milled to the point where it's used in the factory is of a similar order of magnitude and this is also true of the synthetic naturals.

We made one last test and that was perhaps not terribly significant in the sense that it had to be carried out in a very nonstandard way (Figure 25). This was a green strength test on a very small dumbbell cut out from a few grams of guayule which unfortunately shows low green strength in relation either to Hevea or synthetic polyisoprene. Whether or not this is significant remains to be seen. It would have been nice if the guayule green strength had been comparable. It may be just a slight straw in the wind and obviously indicates that larger scale tests will be especially intensified on this aspect because it is so all-important in determining whether there is really going to be a market for guayule in tires.

Figure 26 is a photomicrograph of the remaining portion after removing the soluble portion, and these large black specks are small amounts of gel which, when removed and isolated, analyzed to the same Cis content as the major portions of the rubber hydrocarbon.

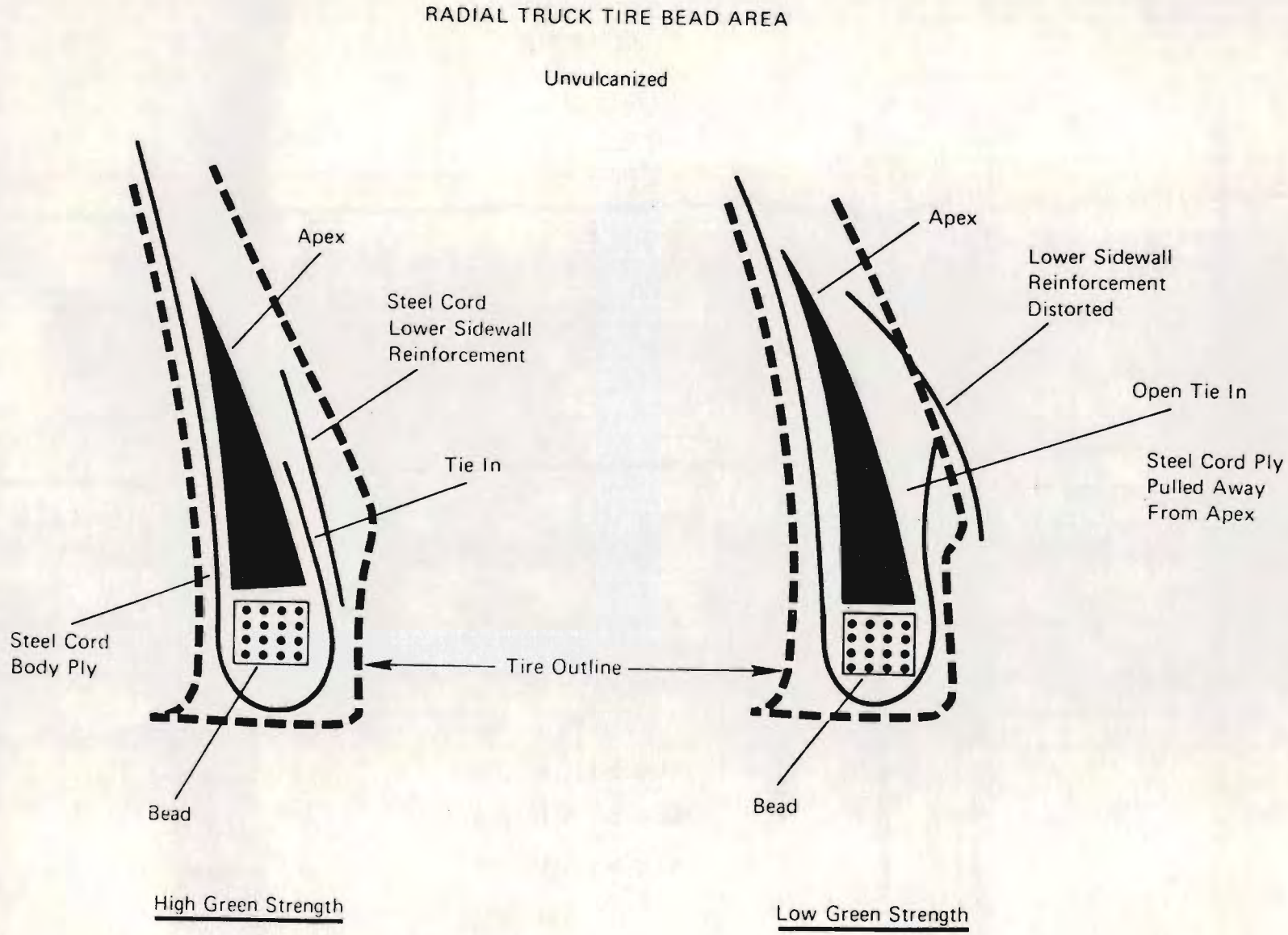

Figure 19. Influence of Green Strength During Construction of Radial Truck Tire

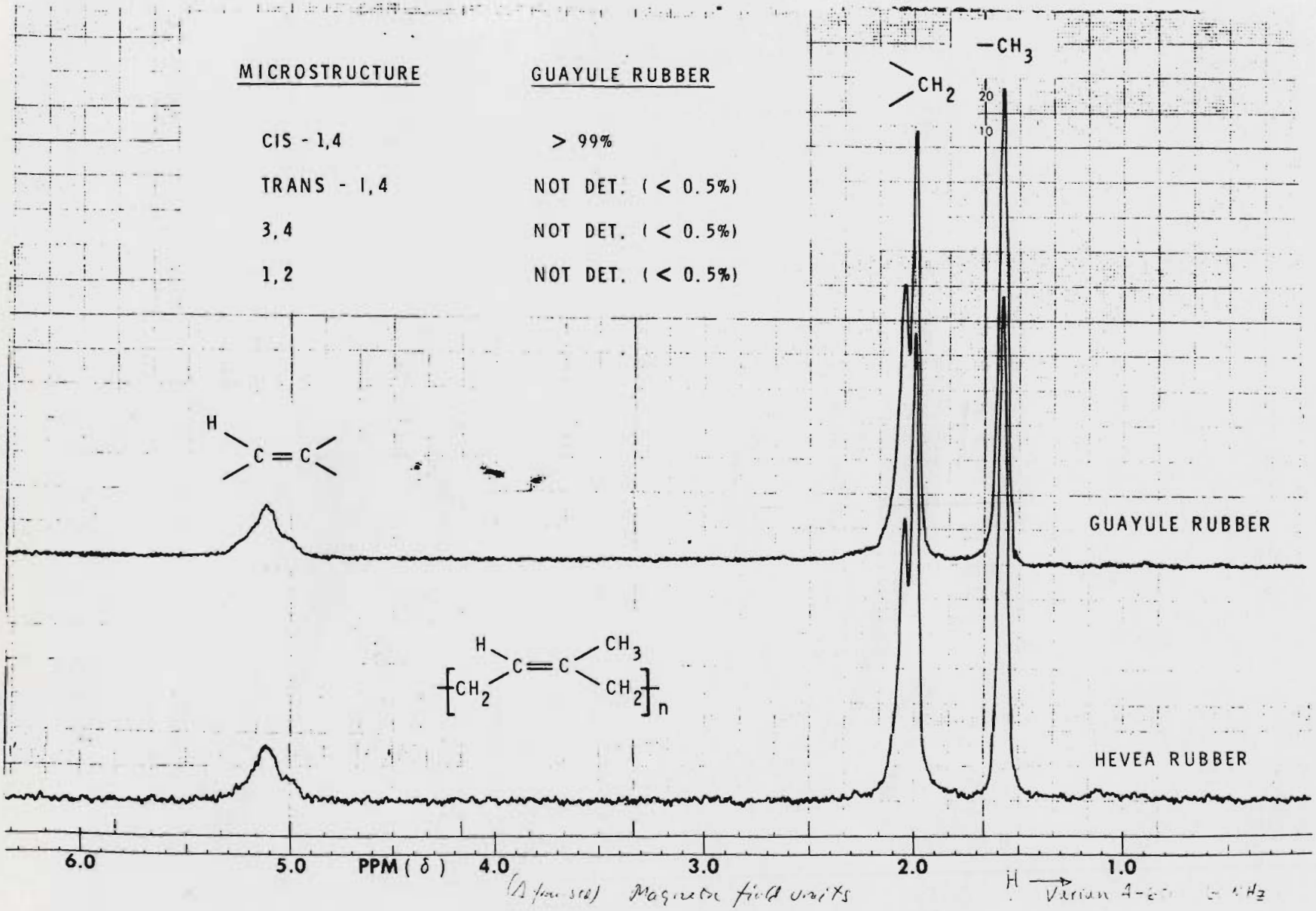
MICROSTRUCTURE
GUAYULE RUBBER
CIS - 1,4
> 99%
TRANS - 1,4
NOT DET. (< 0.5%)
3,4
NOT DET. (< 0.5%)
1,2
NOT DET. (< 0.5%)
$-CH_3$
CH_2
20
10
GUAYULE RUBBER
HEVEA RUBBER
6.0
5.0
PPM (δ)
4.0
3.0
2.0
1.0
(Arbitrary) Magnetic field units

Figure 20

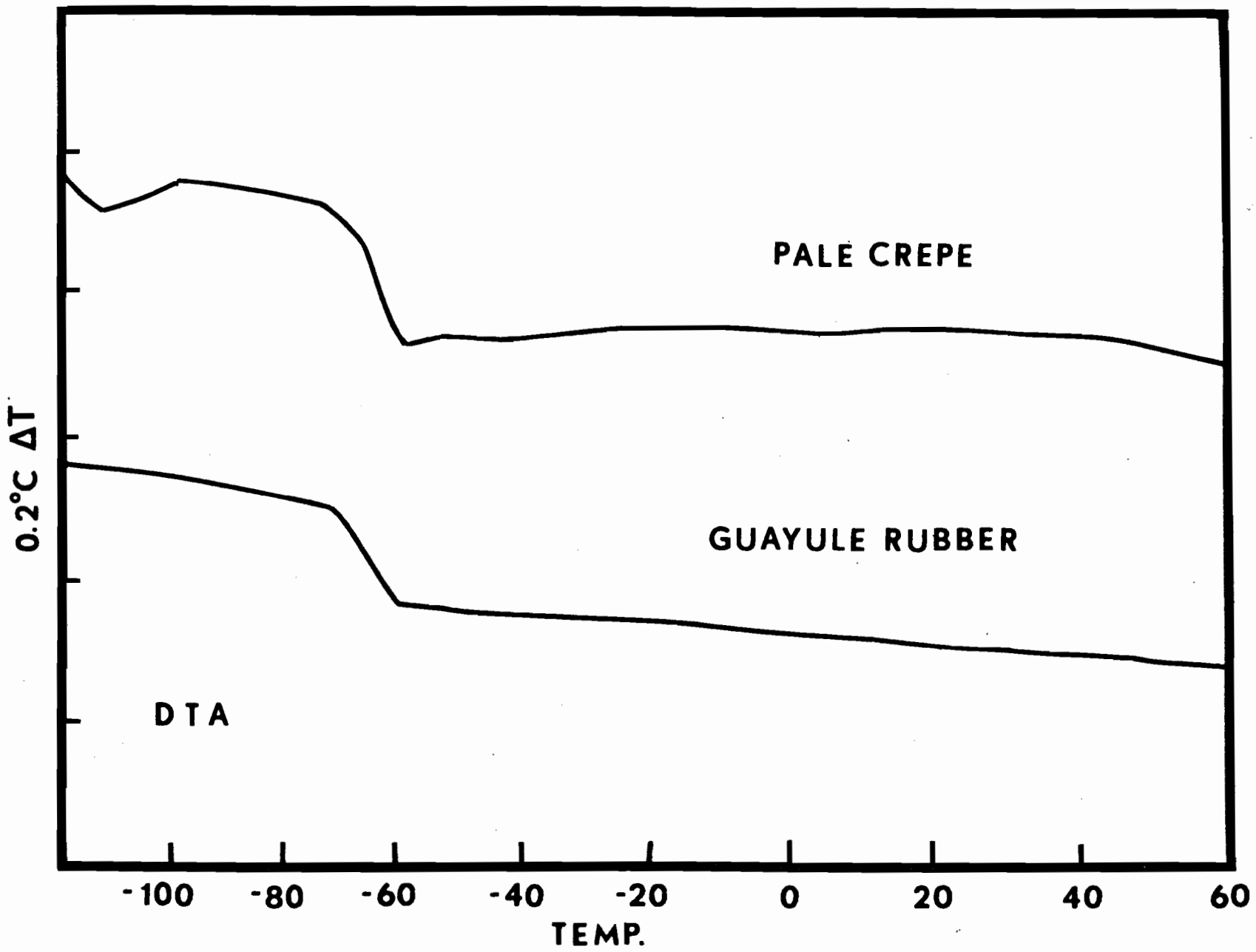
PALE CREPE
GUAYULE RUBBER
DTA
0.2°C ΔT
-100
-80
-60
-40
-20
0
20
40
60
TEMP.

Figure 21

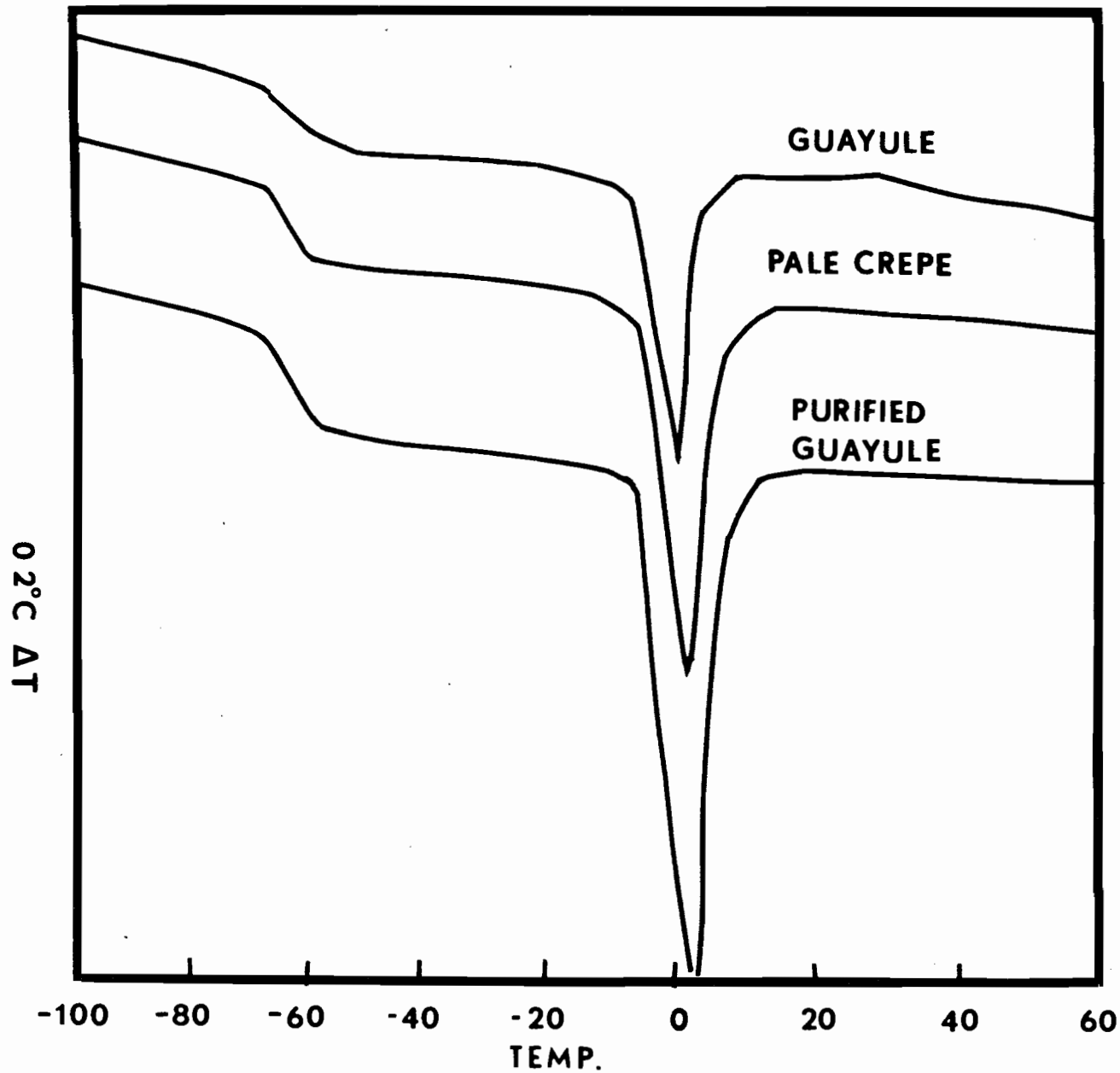
GUAYULE
PALE CREPE
PURIFIED
GUAYULE
0 2°C ΔT
-100
-80
-60
-40
-20
0
20
40
60
TEMP.

Figure 22

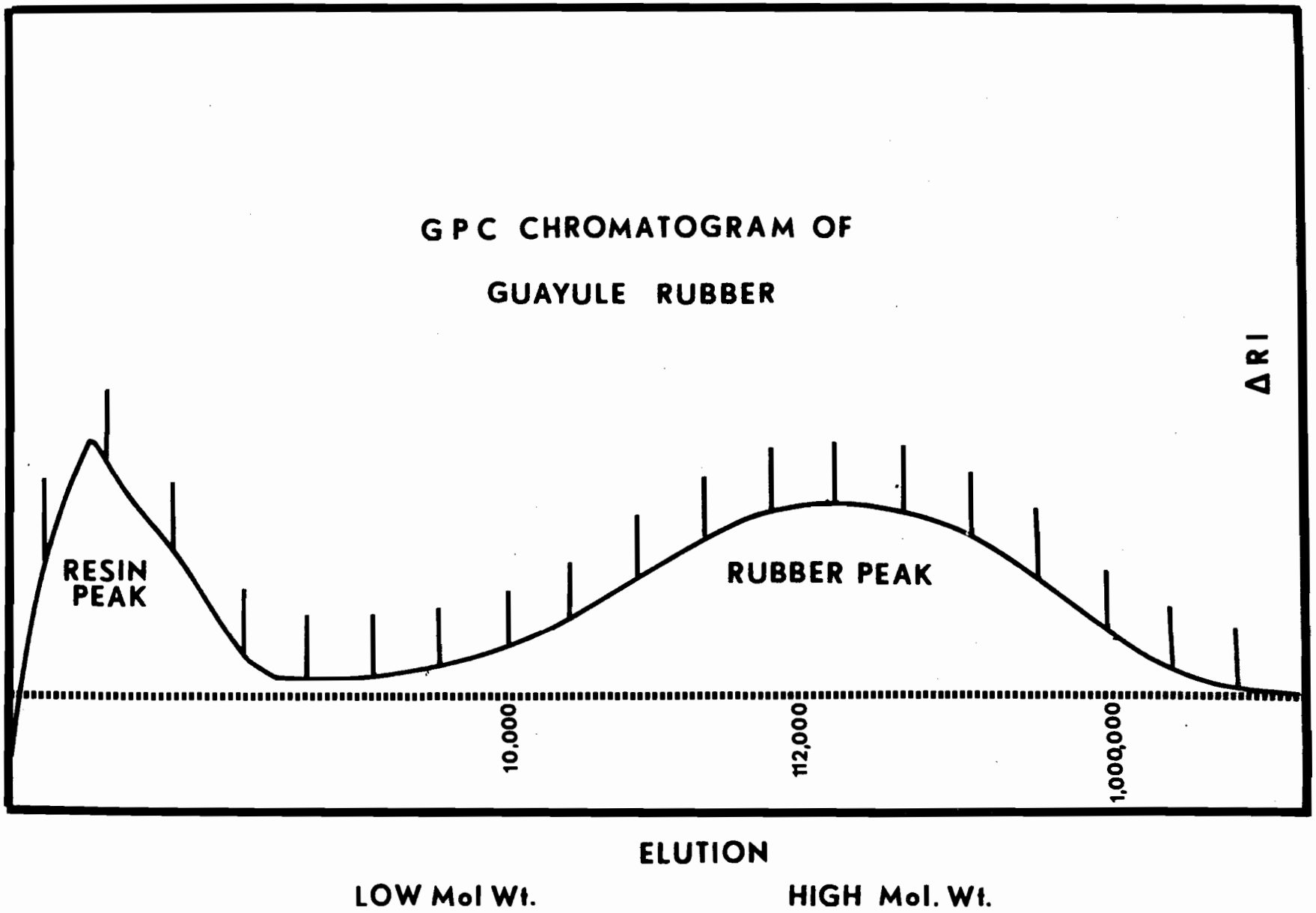
GPC CHROMATOGRAM OF
GUAYULE RUBBER
ΔRI
RESIN PEAK
RUBBER PEAK
10,000
112,000
1,000,000
ELUTION
LOW Mol Wt.
HIGH Mol. Wt.

Figure 23

MOLECULAR WEIGHTS
GUAYULE RUBBER

	$\overline{Mw}$	$\overline{Mn}$	Low Mol Wt fraction
Underesinated Unpurified	464,000	109,000	28%
Underesinated Purified	645,000	148,000	5.7
Deresinated	522,000	136,000	4.3

Figure 24

PRELIMINARY GREEN STRENGTH TESTS ON SAMPLE OF UNCURED 1953 DE-RESINATED GUAYULE (MEASURED NOV. 1975)

	Break Tensile PSI	Break Elongation %
Guayule	22.6	950
Synthetic Polyisoprene	50	1050
Hevea*	97	800

*Tested by slightly different method

Figure 25

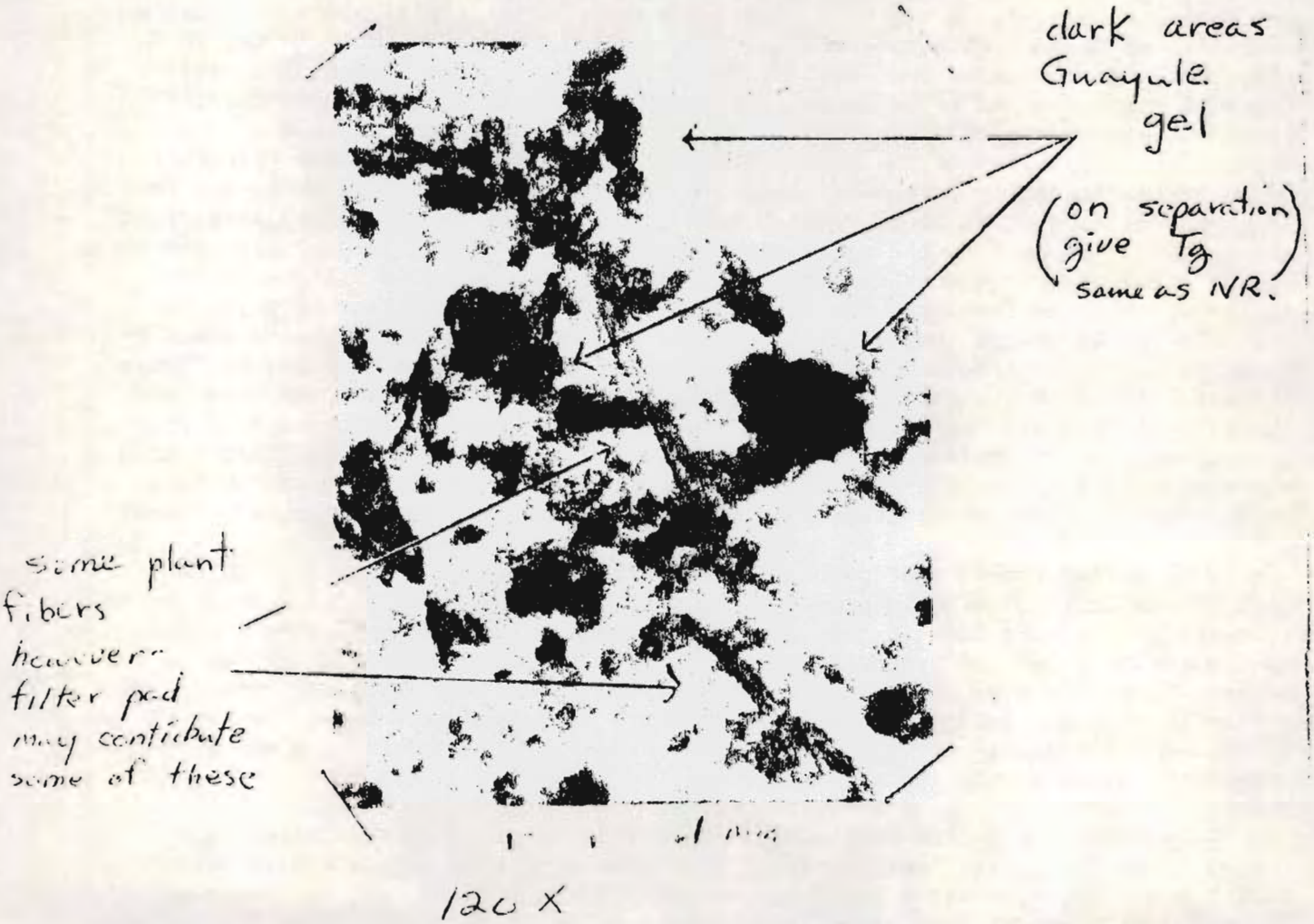
dark areas
Guayule
gel
(on separation
give Tg
same as NR.)
some plant
fibers
however
filter pad
may contribute
some of these
120 X

Figure 26

What might be the indicated directions from the standpoint of consumers if there is indeed a renaissance of a guayule program? Questions which one would like answered (Figure 27) at the earliest possible time are: 1) How good is the very best, not necessarily an easily made but a best version that we now know how to make, of guayule versus natural rubber in the more critical testing criteria; 2) What are the permissible levels of unextracted resin left in guayule when evaluated in these same demanding uses (very important from the producer's standpoint); and 3) How uniformly can guayule be made economically with respect to the amounts and types of nonhydrocarbon impurities. The latter, of course, could only be determined after quite a bit more experience with larger scale growing. There's certainly an analogy with the early days of synthetic natural rubber here, in that, while we were concerned with different parameters, why essentially similar types of questions had to be answered before commitments could be made for the large amounts of capital that went into the synthetic polyisoprene plants. Figure 28 shows a list of the likely steps which we would expect that producers would probably want to pursue--at least, I think consumers would like to see them implemented. The first is to furnish bale quantities of as thoroughly deresinated grades as can be made to the major companies who might become large-scale consumers, and be prepared very soon thereafter to follow up with 500-1000 kilogram quantities which truly duplicate the original sample. It is important to point out that the people who do the evaluation in the big rubber companies are constantly beset by suppliers offering new grades or some change in raw materials; therefore they are always in the process of selecting from such alternatives the ones that appeal to them most. Is it for economic reasons, is there a performance or process advantage, or whatever? Therefore, anyone who comes in to say, "This sample might well do a better job than what you're using now," should be prepared to go well beyond the laboratory stage once the first sample has begun to show promise.

Once having passed that point, I'm sure there would be a question on the part of people interested in producing guayule as to how cheaply the less-than-best grades could be made if they are just reasonably good in performance. This is a question which the synthetic natural rubber producing plants often get into because there are ways of making it--and they are sometimes practiced--that produce a type that is not fully acceptable in the more demanding tire uses, but can be done at a considerable savings in production costs. There would be a somewhat comparable situation in the case of guayule.

Very important is the desirability of developing a projected large-scale cost picture at the earliest possible time because without the carrot of potentially lower costs, there's probably not going to be a great deal of enthusiasm for spending a lot of time and effort on evaluation on the part of any of the major rubber companies.

Comments

Bonner: You pose an essentially insoluble problem. In order to have this guayule rubber studied and considered by major rubber users, we have to produce it on what we would consider a major scale.

Pierson: I would assume that, even on a laboratory scale, sufficiently promising data would already have been obtained so that someone would then be willing to grow quantities that would make a sample of significant size. In other words, this is the dilemma that will have to be faced rather soon: If promising data on quantities that would be obtained from the present, i.e., Mexican, facilities are obtained, for instance, what happens next?

QUESTIONS WHOSE ANSWERS SHOULD INFLUENCE COMMERCIALIZATION PROGRAM:

1. HOW GOOD ARE "BEST" (THOROUGHLY DERESINATED) GRADES OF GUAYULE VERSUS NATURAL RUBBER?

2. WHAT ARE PERMISSIBLE LEVELS OF UNEXTRACTED RESIN LEFT IN GUAYULE WHEN EVALUATED IN MOST DEMANDING USES--e.g., TRUCK TIRES?

3. HOW UNIFORMLY CAN GUAYULE BE MADE ECONOMICALLY WITH RESPECT TO AMOUNT AND TYPE OF NON-HYDROCARBON IMPURITIES?

Figure 27

SOME POSSIBLE STEPS TO STIMULATE CONSUMER INTEREST IN GUAYULE:

1. FURNISH BALE QUANTITIES OF BEST DE-RESINATED GRADES TO MAJOR RUBBER COMPANIES FOR TIRE-TYPE EVALUATION.

2. BE PREPARED TO FOLLOW UP WITH 500-1000 KG QUANTITIES WHICH CLOSELY DUPLICATE ORIGINAL SAMPLE.

3. FURNISH BALE SAMPLES OF "LESS-THAN-BEST" GRADES IF PROJECTED COSTS ARE SUBSTANTIALLY LESS THAN "BEST" GRADES.

4. DEVELOP PROJECTED LARGE-SCALE COST PICTURE AT EARLIEST POSSIBLE TIME FOR DISCUSSION WITH MAJOR NR CONSUMERS.

Figure 28

Campos: How long did it take to get the guayule samples in order to run the GPC?

Pierson: The green strength test was run also with the rubber because we were getting significant different molecular weights in the original natural mature rubber--just five days to be harvested.

RETTING*

Paul J. Allen, Dept. of Botany, Univ. of Wisconsin
Ralph Emerson, Dept. of Botany, Univ. of Calif., Berkeley

*Guayule Retting: A microbial process with potential as a low-cost process for improvement of rubber quality and optimal rubber extraction.

> I have found that if the guayule shrub, instead of being dried and kept dry until milled, is kept in a wet condition properly regulated, before it is subjected to milling, far-reaching changes take place in the shrub, due to natural agencies which make it possible to recover an unusually high grade and uniform rubber product from the resulting shrub. --U.S. Patent 1,918,671 issued to David Spence July 18, 1933.

Nearly 50 years ago it had been shown at the Intercontinental Rubber Company Laboratories that guayule shrub, either chopped material or whole plants, stored in air under moist conditions, underwent natural changes which led to recovery of a markedly higher quality and more uniform grade of rubber than could be expected from freshly milled plants not so treated. The process was termed "retting" by analogy with the ancient practice of retting flax for the purpose of extracting linen fibers. During World War II, the research of one section of the Emergency Rubber Project was devoted almost exclusively to a study of the retting process. Theoretical as well as direct practical considerations were extensively explored, and it was shown that guayule retting is a spontaneous microbial process in which molds and/or bacteria selectively destroy (decompose) some of the more deleterious resinous materials thus permitting production of rubber with lower acetone solubles, higher tensile strength, and other improved physical properties.

It was further established that the microorganisms instrumental in guayule retting require oxygen to develop and accomplish these improvements. Providing the proper environment then was the key to successful retting. In other words, a variety of relatively simple procedures can be employed for retting so long as due care is given to the basic parameters: oxygen, moisture and temperature.

Following is a brief account of 1) the benefits to be achieved by retting, 2) the general methods recommended, 3) the pros and cons of the process, and 4) several avenues for further research. The spontaneous and natural occurrence of retting, its accomplishment with a minimum of machinery and essentially no chemicals, and its selective action upon the particularly deleterious components of the acetone soluble contaminants in guayule all commend retting particularly to the attention of those planning small-mill operations where hand operations may be more readily available than major capital outlays.

Achievements: What is accomplished by retting?

The crude rubber milled from retted shrub is higher in rubber hydrocarbons and lower in resin than rubber from unretted shrub. The compounded product has improved physical properties, with tensile strength increased by 50% or more. Total resin in the shrub decreases and a loosening and decomposition of fiber occurs, with resulting decrease in the bulk of material milled. Losses in rubber hydrocarbon do not

occur but information on the molecular weight and chemical composition of rubber hydrocarbon is lacking.

The foregoing changes are caused by the action of aerobic microorganisms (bacteria, fungi, or actinomycetos). Some components of the (resinous) acetone solubles are actively detrimental to rubber quality. When experimentally incorporated into crude rubber these components cause liquefaction (deterioration). Their selective removal prior to processing is a major function of retting. Since the bulk of the resins act only as diluents in the crude rubber, considerable improvement in quality may be obtained with less reduction in resins than that required by chemical deresination (Figure 1).

The microorganisms involved in retting are natural inhabitants of moist guayule shrub and the identity of many of them is known. Their effectiveness has been demonstrated in inoculated rets carried out under nonsterile conditions and in pure culture experiments.

Representative retting methods

In general, the more finely divided the plant material is the more intense and rapid the retting process and the accompanying heat production will be. Furthermore, and particularly noteworthy, the more rapid the action the more precisely it must be controlled. Novices are urged, therefore, to explore the possibilities of retting first with the simplest procedures such as bale retting.

Table 1. Approximate conditions for representative rets, all starting with parboiled and defoliated whole shrub.

Type	Plants	Moisture, % Wet Wt. Basis	Temperature °C	Aeration	Time	Conditions
Bale Ret	Baled Whole	25-40	40-55	Automatic	21	Protected Bodega storage
Floor Ret (unturned)	Cut to 1"	35-50	<55	Automatic	7	Spread 1" deep
Drum Ret (contin. turning)	Cut to 0.5" & crushed to 0.004"	52±3	30±3	Forced	3	Rotating Drum with artificial cooling

Pros and cons of retting

The main contribution of retting derives from its action in preserving rubber quality between field and mill. In an operation which does not accomplish this by other means, retting can play a crucial role. Moist shrub is subject to microbial action, and retting may be simply a matter of holding such shrub to accomplish coagulation of rubber under conditions which also produce decomposition of deleterious resins and decrease the total mass to be milled by as much as 1/3. Necessary storage time could thus be used to accomplish rubber quality improvement. Milling time is shortened because of the thorough hydration and loosening of all wall structure and decreased mass fed to the mills.

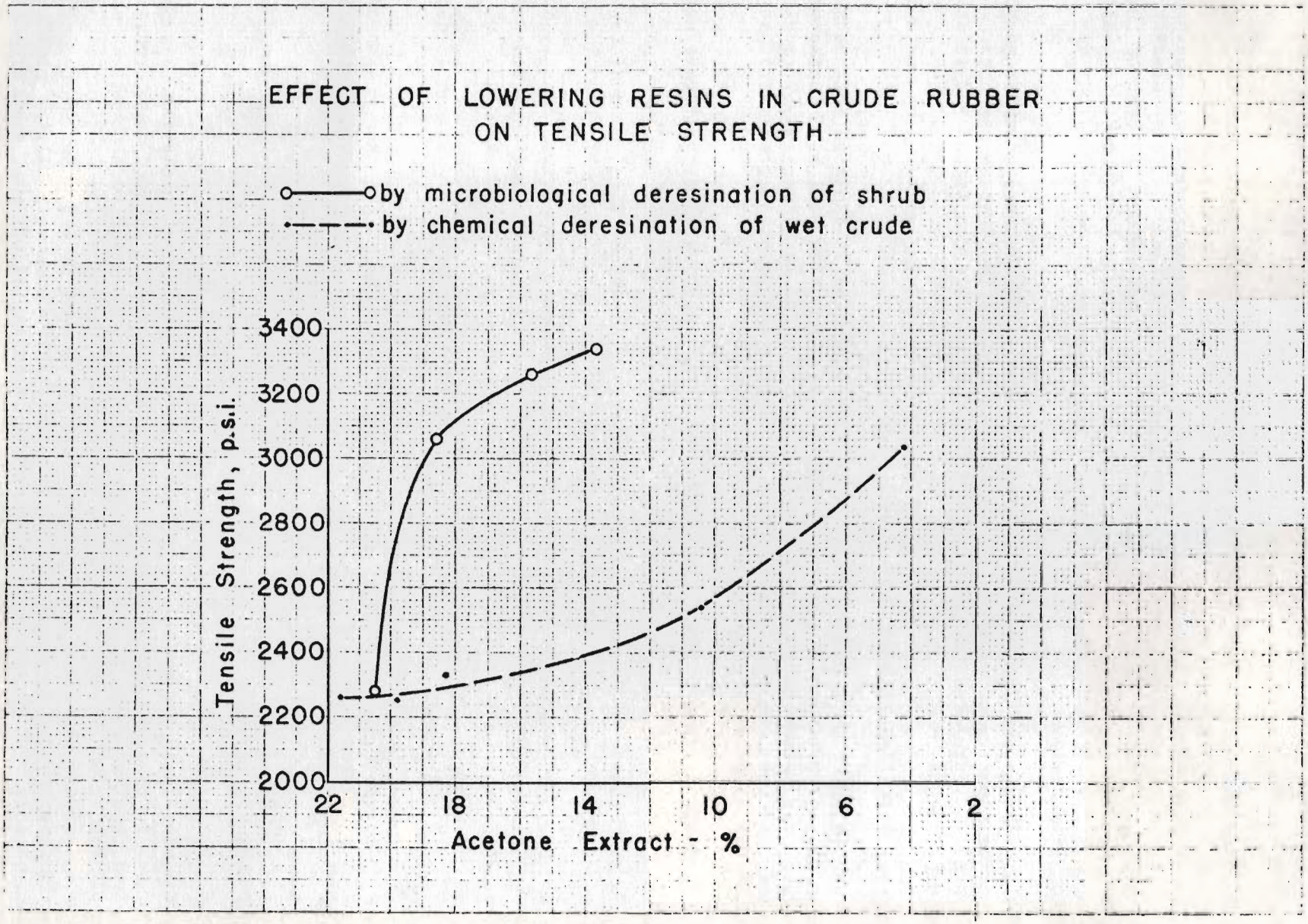
EFFECT OF LOWERING RESINS IN CRUDE RUBBER
ON TENSILE STRENGTH
by microbiological deresination of shrub
by chemical deresination of wet crude
Tensile Strength, p.s.i.
3400
3200
3000
2800
2600
2400
2200
2000
22
18
14
10
6
2
Acetone Extract - %

Figure 1

Because of the specificity of biological action, decomposition of resinous hydrocarbons and other non-rubber components is not accompanied by loss of rubber. Comparative studies of the chemical nature of the rubber products are needed.

If recovery of resins is important, retting would limit the efficiency of their recovery as a by-product, but would not eliminate them. Recovery of dry matter as fiber would also be reduced and fiber quality might be impaired. The holding time between harvest and milling would be longer for some kinds of retting than the minimum required for rubber coagulation. Retting should be eliminated in any program directed toward latex recovery.

Areas for research

We do not know the identity of any one of the resinous components which cause rubber deterioration. Gas liquid chromatography would now permit in a short time separation and characterization of these compounds which was impossible in 1945. Any program for guayule rubber production needs this information as a guide and possible help in quality control. Identification of the active compound(s) would also permit identification of the place and mode of deleterious action and possibly permit circumvention of the loss or replacement of retting by a more direct approach to preventing rubber deterioration. Are the benefits of microbal and chemical deresination (acetone, acetic acid, etc.) similar or additive? Where in the plant do the deleterious resins come from, and could they be reduced or eliminated prior to processing? Further knowledge is needed of the action of specific microorganisms known to be effective in improving rubber quality.

The conditions required for successful retting are well explored, but work will be needed to establish the most practical way of achieving those conditions in the social and economic setting in which the industry operates.

Retting, a natural microbial process which promotes coagulation of rubber in the shrub, selectively eliminates deleterious acetone soluble impurities, and reduces deterioration of rubber quality in processing. This could be of value, particularly in medium and small scale operations. If production becomes a cottage industry, retting might be a useful adjunct in processing shrub.

EXPERIENCES IN GROWING, PROCESSING AND MARKETING GUAYULE RUBBER

Hugh H. Anderson
Pacific Rubber Growers

Much evidence has been brought before us in different categories of accomplishment, together with opportunities for further improvement in seeds, nursery handling, planting and land management, and harvesting. Both achievements and problems have been exposed in extraction and deresination.

I have been asked to relate my personal experiences, as they bring a different point of view. I am not a scientist as many of you are, but a business man with training and experience with that emphasis. Perhaps my viewpoint will prove useful. I hope so. Generally, I would like to emphasize the success of our extraction process by pointing out that I, as a business person and not an engineer, have extracted rubber that has been described as "having qualities equal or superior to Hevea rubber," using Manzanar Relocation Center techniques in a lab that I built and used. I propose that rubber from the guayule shrub is low cost and high quality at this moment and is likely to retain these competitively favorable attributes for a long, long time. I agree that guayule rubber is subject to great improvement in per-acre yields and the current methods of harvesting, both of which are manifestly on the way.

At the end of the war which made the Emergency Rubber Project necessary, I was able, with a group of associates, to purchase the last remaining 1,150-acre stand of shrub on the Phillips Ranch in Southern California. Because of the excellence of the land on which it grew, the shrub was large and beautiful. It had only 9% hydrocarbon by analysis. Nevertheless the rubber totalled several hundred thousand pounds.

We built an extraction mill. As soon as we were confident that we could deliver according to order, I took 200 pounds of our best commercially produced rubber to the Wrigley Gum Company in Chicago. We had previously been given verbal commitment by Wrigley for orders for all our rubber at $3.00/lb. but were given a written order for the first hundred tons at only 90¢/lb. This was adequately explained--a matter involving the Company in certain embarrassments--and we accepted their explanation, still planning on the $3.00 figure. Their purchasing agent was ecstatic over the quality of our rubber. Then he told us that Wrigley had just been given federal permission to buy from the U.S. stockpile at 17-1/2¢/lb. He offered us a few cents over that, but we had engineered our plant for a one-time operation, knowing that we wouldn't replant on the high water retentive soil of

the Phillips Ranch. Also we planned our factory operation as labor intensive, for a rubber cost of 20¢/lb. Quantity sales in this instance would increase our losses, not reduce them, so we came to no agreement with Wrigley. Meanwhile the government in this period of strategic war material control would allow us to sell our material to no one else. We were able to sell the land at a profit and we watched our buyer plough under the guayule, plant barley and obtain bountiful crops--for far greater yields than he had ever harvested previously in the immediate area. We had proven the feasibility of commercially extracting rubber with our process. We had taken the operation out of the lab.

Years later, in 1964, after I had talked with many persons and businesses that might be interested in using rubber and after I had handed out all my rubber samples, the question arose: Where to get more? I decided I would build a mill and import wild shrub from Mexico. By placing the raw rubber in commercial hands for testing, I could gain slabs that would be used for samples. The procedure was a bit complicated. From shrub that was very dry--a month out of Mexican soil and hardly chosen for its high rubber-bearing quality--I extracted adequate quantities of rubber for testing. This rubber was placed in the hands of four different manufacturing companies that were processing rubber for the market. They were asked to tell me in writing what they thought of it after practical testing. I reasoned that this was better than placing it all in one commercial testing laboratory. I wanted opinions of several manufacturers and especially of several potential buyers. I received the opinions and I will report later on them.

I also visited the guayule plantings in Turkey and Spain. Spain extracted all the Turkish-grown rubber as well as their own using the Salinas improved process. By invitation of the government, I went to Western Australia where they did field testing for us, but Frank Kageyama, who accompanied me on one visit, later discovered that the seedlings had been planted in dry sand without water. Only ten percent of them survived. However, we found that there was moisture five feet below the surface and we concluded that the surviving seedlings with at least a half-inch crown diameter had done very well. The smaller seedlings--the other 90%--didn't have what it takes to reach the moisture level at planting time. In another planting where not one plant grew, Frank found that each seedling had been suspended in a hole by a pinched-up dirt collar. Not one root touched soil. The Australian government then mistakenly concluded that guayule would not grow there. Then we discovered a patch of guayule shrub that had been planted in 1942 and was growing very well--which, incidentally, solved one of our fears. It indicated that kangaroos and rabbits leave it alone. This 18-year-old shrub was thriving in nine inches of soil resting on hardpan.

May I say at this time how very grateful I have been for materials and information that I have been given by many in this audience. I also have Major Kelley's private rubber library. I spent much time with Paul Roberts and attended all of the meetings of the governor-appointed California State Guayule Committee, chaired by Carlyle Thorpe, and I followed the Federal Natural Rubber Advisory Committee chaired by Dr. David Spence. Dr. Bradley, who was formerly Director of Laboratories of the U.S. Rubber Co., was a close associate in building our mill at Banning and was most helpful with advice and experience. There are many more, I regret to say, to whom I can extend appreciation only in retrospect, such as George Miller and especially Dr. Robert Emerson.

You may be aware of the position of E.F. Schumacher, the great British economist who suggests alternate action in many of our industrial uses of energy. This

idea is not sacred to only economists. All the rubber manufacturers that I know are, without exception, of the same mind.

We may be here today to examine a possible alternate use of energy in the rubber industry, namely solar energy by a shrub, so let's look at costs and qualities of guayule rubber as I know them.

Early costs were set forth, based on several decades of experience by the Intercontinental Rubber Company, in the figures of their Mr. Lee, Accountant. Using their figures, the experience of the ERP, and of Manzanar, we are able to suggest the following significant cost reductions:

1. Land was 25% of the total cost. Fifteen years ago I was offered 200,000 acres of Australian land at no cost at all. It was good land for guayule. Today that same arrangement should be possible, as I learned last year from the present government in Australia.

2. Weeds were controlled by hand hoeing. When we took over the Phillips Ranch there were 100 men hoeing weeds. We eliminated permanently the morning glory pest and controlled other weeds with only three men, part-time, using Salinas-developed methods.

3. Intercontinental stored baled shrub for rubber coagulation before they milled. Instead, we mill as soon as we can get the shrub out of the ground and into the factory--no storage.

4. Pebble ball milling was handled in batches. Our process is continuous with a system that requires no stoppage of operations even when one of the Jordan engines breaks down.

5. Rubber recovery from the shrub was established as "not much over 65%" by conversations with Señor Roberto Ross, formerly manager of the mill at Torreón for Intercontinental. His counsel combined with the report of Miller and Kaley on the five mills operating in Mexico during the war, made our extraction process appear to be very low cost by comparison. We expect to commercially recover 99% of the rubber. Laboratory runs by Robert Emerson and Shimpe Nishimura showed occasional recoveries of over 100% as established by chemical analysis.

While it is not possible to recite actual costs without the experience of operating, we feel with conviction that the cost of rubber production should not be more than it was 40 years ago in spite of rising costs due to inflation.

But we have other means of mitigating costs. In working with Crown Zellerbach Paper Company and Adamson Engineers, we find our bagasse is saleable. Mr. Olmstead of Crown Zellerbach on September 4, 1943, expressed the opinion that if the bagasse were available in adequate quantities, its value for paper pulp could be expected to pay the cost of extracting rubber. This statement is taken from the notes of Robert Emerson who went to San Francisco with samples of Manzanar bagasse.* Adamson Engineers, to qualify them for an opinion, built a large paper company utilizing sugar cane bagasse as the principal constituent of raw material....so their favorable opinion was significant.

*Two-three tons of pulp for Kraft paper per ton of rubber priced $342/T. in Sept.'75.

In addition, in an area in which we, as yet, have done no work, we are told by Dr. Irving Feustel and Mr. Ken Taylor that possibly the resins can be made to show values equal to those of rubber. We know that Dr. Bradley gave perfume from the resins that his wife used as Christmas presents. I was told in Spain that Dr. Eloy Dorado Bernal had obtained a valuable hormone, but I later received a letter saying the substance had only 20 carbon atoms and therefore was not of the family of hormones that was originally thought. I am saying this to correct any misunderstanding that I may have caused by the first report.

In re-emphasizing two points that I have made, I ask, "What is continuous operation worth in contrast to batch operation? What is the value of being able to harvest any time of the year with no storage expense, but instead proceeding directly to an extraction process that brings forth nearly 50% more rubber recovery?"

Our process was examined by C.F. Braun Engineers who design and build rubber factories for synthetic rubber production. The company that employed Braun did so in order to establish that they could proceed to provide us with a five million dollar backing. Braun gave them the green light to go ahead. Some Australian political considerations later stopped us. Also Dr. Vogt, who was in charge of building the first synthetic rubber plant in Southern California for Shell Oil, gave us his encouragement after studying our operation. He said that he believed that we would be in business long after synthetic rubber had gone.

However, we think quality is our rubber's greatest virtue. For identity among other rubbers, we call our rubber Parthenium. May I give some comparisons? The following figures and statements are from outside sources. We gave samples of raw Parthenium rubber to rubber processors who have given their observations.

From our factory rubber that was produced at Banning, California in 1947:

1) Mr. Bilheller of Muehlstein writes that men in his company in New York were favorably impressed.
2) Dr. Bradley said the rubber was superior guayule. He had it tested at his lab at U.S.R. Co.
3) Mr. James Holm, President of Kirkhill, Inc., stated that had the rubber not been 12 years old, it would have provided results in processing equal or even superior to ordinary smoke sheets.

From the Anderson lab of 1966 are the following:

1) B.R. Snyder of Vanderbilt Company of New York--feels offers of a cent or so a pound premium might be paid over regular smoke sheet prices...for limited uses.
2) Robert H. Pratt, President of Crown Rubber Co., states the rubber has excellent hand with tensiles from 3,600 to 4,200 psi which he finds excellent.
3) W.M. Moser of the Reeves Rubber Co. states the ease of processing are impressive. He finds the physical properties fall well within the range of those obtained from Hevea Rubber. But he wants it at a lower price than plantation rubber.
4) Mr. Fred D. Williams, chemist for Schultz Rubber Products, says he finds that in a number of properties superior to Hevea Rubber, particularly processing, moldability, building tack and mixing. Tensiles up to 4,200 psi.
5) Dr. C.E. Bradley gives his opinion of guayule rubber in general from 35 years experience in working with it and after observing the work at Manzanar and Banning, Calif.

Eleven million short tons of rubber were used by the world last year. At 30¢ a pound the value would be six billion dollars. There was much sold for less than 30¢ and some for more, but if the figures are off one to two percent, it is still a large market. If one could produce that much rubber on a nearly cost-free basis by selling his byproducts advantageously, the endeavor would be worthy of the most prudent investor. Winston Churchill did organize a control over rubber in the early twenties when the price was set at $3.00 a pound. It may be of interest that when I was in Kuala Lumpur, Malaysia last year, I was told by government officials that 20% of the plantations had been destroyed, mainly for the purpose of replanting with oil palms for greater economic gain and for growing food. The world's supply of Hevea has come from that area where 93% of tree rubber is grown commercially.

Parthenium rubber compares favorably with existing natural rubber, or synthetic rubber, in cost, quality and breadth of commercial applications. It is produced with a small percentage of the labor of tree rubber. It grows on lands of limited benefit for other crops, between the 20th and 40th parallels (and is not limited to a narrow strip of land close to the equator in very moist climates with plenty of 40-50¢ a day laborers available--as in tree rubber). It will adapt to good lands, as long as moisture control is possible. It has byproducts that will cover virtually all costs. Therefore it would seem that the successful future of Parthenium rubber is clearly assured.

It will be good to have arid, Indian lands put to constructive and beneficial advantage of both those whose entrepreneurial skills lead the way, and the land owners. I would suggest that large companies begin their building for a future rubber supply for that time when petroleum derivatives are priced at prohibitive levels for making synthetic rubber. As there won't likely be any rubber from the guayule plant for five years, the time to start is now.

This conference has presented the opportunity for expression that guayule proponents have long awaited. We have known since Emergency Rubber Project days that guayule was likely to provide the new rubber, but it took economic conditions to give us a platform.

Rubber from guayule is in the hands of the future. I suggest the future is closer than we think.

Comments

Question: (Bonner) Hugh, you're beating the drum for guayule as a dry lands crop and I think before we can realistically accept this sort of a designation, we do have to have more detailed information than anyone has provided on rubber yield per acre, the function of amount of water applied. It hasn't been demonstrated to my satisfaction that economically reliable yield of rubber can be produced from guayule as a cultivated desert crop.

Comment: (Anderson) James, my prime function is that in the extraction process, as you know, and I'm afraid that we're going to have to leave it up to some of the agricultural experts to do the dry land planning for us.

Question: (K. Taylor) Using caustic in the work that we did on the Emergency Rubber Process, we found that the aging characteristics of crude guayule held in the bale that had previously been treated with caustic were very poor. We'd be very interested to know how you overcame that.

Anderson: I'm not quite sure that I understood you, Ken. You say rubber held in the bale?

Taylor: Yes, baled as in this block that's here on the table. The crude rubber which had previously been treated with caustic in the operation of recovery showed poor storage characteristics.

Anderson: Do you mean the bales being stored?

Taylor: Yes, the bales being stored.

Anderson: Oh, well, we wouldn't think of doing it that way.

Taylor: No, I mean the bales of the crude rubber such as this bale here.

Anderson: I see. Let me tell you a little story here. About a month ago this piece of rubber was raw rubber. At the suggestion of Dr. Vietmeyer, I had it tested and had it compounded on the gum formulation by one of the local rubber companies. The tests were very low, I'll have to admit. The tensile was only 1600 pounds. I have a letter to this effect explaining why and so on. But I think it must be pointed out that that rubber was extracted 28 years and has been held in the raw state all that time. Does that help? I might say that when we had some rubber 12 years old we took it to the Kirkhill Rubber Company and had it processed. It was some of this same rubber. Jim Hone, the president, wrote me a letter to the effect that had the rubber not been slightly oxidized, it would have handled equal to or superior to *Hevea* rubber. As it was, it was highly satisfactory for all of their process needs.

Emerson: I may be able to clarify this, I'm not sure. I've been reading the relevant papers recently. The manner of storage was at least looked at by the Manzanar group when this process was worked out, and the statement in the literature is that the shelf life of rubber extracted in this way was exceedingly good but it is not stated whether it was baled. Personally I doubt if it was, but I don't think there was that much out of the Manzanar Project very often. Now you might be able to clarify, Hugh, I'm not sure, but the point is that this was at least looked at and under the conditions it was looked at the stability seemed to be better than in many cases. There were some other additions to the process. The deresinating that they used was an acid process and that may have contributed to stability subsequently. That's difficult to know and I don't think that the problem is treated anywhere in the literature. It's clearly a place where more research is needed soon.

Anderson: Yes, Ken, that might help to clarify it a little bit. In our deresination process, and this is for Mr. Campos too, we always used acetic acid. Whether it was right or wrong, we got phenomenal results. So this may have helped to offset any injury that came from the caustic. It was done to make milling roughly one-fifth the time required for ball milling, and possibly even less than that for equal results, or the 99% recovery.

Comments

George A. McCallum, son of W.B. McCallum

I think I ought to consider myself the original ball mill. As you know, one of Dad's methods of analysis was to cut off a piece of the bark and chew it, but as long as he had me or one of my brothers around, we were the ones who chewed it. I can remember going down to the field and he'd look at a plant and say, "That looks pretty good; here, have a piece and chew it." So my recollection of guayule starts with its taste. Then the rest of it was really chasing it around the country except that I really didn't chase it in Mexico because I wasn't born yet when the unsettled conditions of the revolution made it obvious that they should try to grow it in this country. Prior to that time they hired my father who was a plant physiologist. I think it's quite fitting that this Conference be held here at the University of Arizona because his first job after he got his degree was working here at the University. The rubber company hired him away from the University to work on this wild plant. He had a number of problems because, as you know, when you pick the seed and try to germinate it right away, it will not germinate. Here was a plant where the roots spread out. How are you going to raise it in a nursery? There were a large number of problems plus the fact that there are so many different variations in the wild plant.

He segregated over 1300 different variations. I think he did something that no one at that time could anticipate but it wasn't very good. Any of those that were variable which meant that they reproduce sexually, he threw away because he wanted consistent results in obtaining rubber. So he ended up with the varities that reproduced asexually, but gave consistent results. They did begin a program in the late 30's of trying to breed, but here again the ones he had to start with were the very ones which he had chosen because they were consistent. About that time the federal government had stepped in. They had come to the conclusion that maybe they ought to go back down to Mexico and bring up some other varieties, some of those he'd thrown away. But with the advanced pace of the war, things were changed. It's amazing to me to see the large number of people who worked on this over a period of a few years, and advanced the know-how because the federal government was smart enough to bring in specialists in all fields. Dad was originally a plant physiologist, and he was the man who worked on guayule until that time, as far as commercial production was concerned. But after hearing reports at this meeting, it still looks as if there's a great deal of work to be done in tying in the different characteristics of the different varieties by making crosses, and perhaps developing plants which will grow fast under conditions different from those that were used in the rubber project. Because there again you had one or two varieties that had specific characteristics, it might well be that good rubber producing plants can be produced that will grow under different conditions; I think all of this needs to be investigated.

It was mentioned that when father moved out of Mexico during the revolution, they forbade him to take any seeds and he carried some in his tobacco can. I might say that that was not the only trip he made to Mexico, because in that tobacco can he had only a few varieties. Before he got through, as I indicated, he had more than 1300 varieties and I hope the federal government, at least the Border Patrol, does not feel that they can penalize the second generation. But if I do say so, he was a very good smuggler.

Comments

Ken Emerson

I was 10 when the war began and 15 when it ended. For the four years from 1942-45 our family pretty much lived guayule one way or another, because we were constantly involved in the various goings on that were required to start and run the Manzanar Project. Things have been said which I appreciate very much about my father's role in the Manzanar Project. I think that due credit should be given at this point to the several Japanese co-workers in that project, some of whom were exceedingly clever and talented men. The project would never have gotten to the place it did were it not for the participation of people like Shimpe Nishimura, Akura Acoma and Frank Irasawa, and a number of other people involved in that project. It's true my father was a person who got it off the ground and perhaps kept it running, but it had to be somebody outside of the camp. Without those other people, it would not have accomplished anything like the amount that it did.

There are some pretty serious differences in aim between the Manzanar Project and the ERP. The Manzanar Project was a bootstrap operation from the first, with no budget and it therefore was looking to different things in certain ways--and was not able to do the kinds of things which ERP could do. It was not trying to do a production line operation, so that some of the things needed to be compared carefully when you look at the two. I don't mean to suggest that one could not use the techniques that were used at Manzanar at production scale; I think Hugh Anderson has dealt well with that and I think that these can be done. The only things that I can add to this are reminiscences of which there have been a great many. I well remember the amounts of rubber, the kinds of things that hung around the house that Hugh has been bringing out of his pocket in the last few days. We have those things by the bale in the house. When we began to find out what quality rubber this was and to vulcanize it, to get samples Bob went down to the U.S. Rubber Company and worked with Mr. Bradley. The only thing they could find for a mold at first was an old mold which made six rubber airplane tail wheels for what must have been a very small airplane. At one time, I'm sure that there were a dozen of those things in the house in various colors. We had those airplane tail wheels all over the place, and all sorts of different things were done to use this as a test. The other thing which I think they eventually found was a milking machine cup. We had a lot of those around the house; no cows but lots of milking machine cups. So there were a lot of these kinds of things done.

I think that there were probably gaps in communication between the ERP and the Manzanar Project at times during the war, and that this was probably an inherent situation. It would have been difficult to achieve any more than was achieved. But I think one of the things that this Conference has done is to bridge those gaps pretty thoroughly, and I'm very glad to see it.

Walter Fetterer

One of the requirements of getting a guayule project off the ground is convincing a Congress and a State Department that we should become more self-sufficient. Right now they're fairly intent on making us very dependent on Russia for natural gas, and on China for oil, because China has probably the biggest untapped oil reserves in the world. They have a lot off their mainland. Guayule will have a hard time getting off the ground because they don't seem to want to make us self-sufficient in any area. I mention this because I think it has been a problem with guayule all along.

I was associated with the breeding and with the agronomic groups. My office was next to Del Tingy's office, so I spent a bit of time with him. This crop can be mechanized; it is a U.S. crop. It can be grown. I look at it as a very feasible thing as far as U.S. agriculture is concerned. With respect to plant breeding, there are many problems that haven't been dealt with, and in this connection I'd like to say that all your tests on rubber on its tensile strength and everything else that has been done be considered as lower bounds. If you give a plant breeder a goal, he can increase these things. There's been no selection, as far as I understand, for higher quality, i.e., to take out the resin. There's no reason the plant breeders cannot take most of the resin out.

The other thing is the higher rubber percentage. For example, if you go to sugar beets as an area. One company was in serious trouble; they were going out of business unless they could get another percent of sugar. What did the breeder do? He told them how to do it; not only did they get a 1% increase in sugar percentage, they got 1-1/2%, and they also got an extra ton of beets per acre. Another example in sugar beets is that people would like to harvest them a couple weeks earlier. Even the plant breeder at the sugar beet company said it couldn't be done and get as much sugar. But the trouble was that he had 43 hybrids in a test there and several of those hybrids had already made him a liar by the end of the year. So you could harvest it two weeks earlier and get more sugar than the standard variety. These are all possible.

Another thing you want to look at is higher yields. If you look at some of the work that John Lundquist is doing at the University of Wisconsin, and look what Powers did with Colorado Red, the tomato variety in Colorado, what Placedit has just done with potatoes, and after all, potatoes have been around for a long time. If somone comes up with a new strain that yields 50% more than the standard, that's a breakthrough. And he just did it. In other words, instead of getting 370 bushels per acre on Long Island, he gets 540 now. That's 100 hundred-pound sacks per acre--and that's a lot of spuds. The breeders can do it. Look at the agronomist, the breeder, and all the other plant scientists together and see what they've done to corn yields in 40 years in the U.S. The wheat average is up five times over what it was 30-40 years ago. The corn average is up at least four times over what it was 30 years ago; these combined practices can really get the yields. Don't worry about getting more production. The breeder will give it to you if you give him the money and the yields.

There's another thing that is troublesome in the milling. These are the leaves. Maybe you could breed for leaf drop but let me use a better method. Certainly if it's going to be used in Indian agriculture, let's take sheep or goats and bring them in to defoliate the plant. It doesn't cost you anything; you can see the sheep and goats eating the guayule on the range in the Big Bend country. So why won't they eat it when grown under cultivation? I would use sheep and goats to defoliate most of it. They won't get it all off but there would be fewer weeds. You could use guayule as an alternate pasture in your dry areas. If your regular pasture doesn't come through, instead of harvesting your guayule this year, use it for pasture and harvest it next year. Unlike most other crops (the annuals) guayule is an extremely flexible crop.

Another thing that can be done with guayule which hasn't been tried is to grow mixtures of crops. Many years ago, before we became so specialized in the U.S., we always had watermelons in the corn patch. That was called crop mixtures. You can put cucurbits, desert squashes and other plants between the rows. These are

all possibilities. On a world-wide basis, I might back up just a little bit. Professor Neal Jansen put out a paper on a multiline theory in the early '50's and I guess most people thought he was crazy. You know you don't grow mixtures of crops, but now everybody's beginning to accept him. Maybe that's the way with guayule--you were just 30 years ahead of your time in getting the research out, and maybe it can be used at this time. So if you get too far ahead, people won't use it. But in any event, he put out this multiline theory, that you grow five to ten varieties and alternate them. They all have different characteristics except for yield. They all yield the same, and if a smut comes through or a rust comes through, it wipes out some of the varieties but not all of them. Not only that, by having them interspersed the disease doesn't spread as fast, so you gain many, many ways. You can also grow them in mixtures. He has results showing that if you grow Clinton Oats in a mixture, it gains eight bushels per acre. Its neighbors lose only two, so you get a net gain. This is on half the space so you'd have to cut that in two, thus, you get a net gain of three bushels per acre just by growing a mixture. As I say, he started this years ago. Now there's interest in this. Nigeria is setting up a big conference in South America. They use multiple cropping, corn, casava and these things, and there is multiple cropping going on around the world. So I would say that multiple cropping is an area that should be researched.

Another use I could see for guayule is as a shelter belt. Most of you forget--well, I guess most of you don't--the dustbowl days. The dustbowls are going to be with us again, you can bet just as certain as I'm standing here. But if you had guayule planted every two or three miles, you could harvest it--or a quarter of it--in a four-year cycle, i.e., harvest one fourth of it every year and maybe replant a quarter. This could be used as a shelter belt and at the same time you have a shelter belt which yields an economic gain. Of course, there'd have to be a mill in the area and things like that but these would have to be worked out. So look at it as a shelter belt, because here is a crop that can be used in that way.

You'd need to get cold resistance to get it up into the areas where you'd want it. Western Kansas, Western Oklahoma, and Eastern Colorado are the areas I would be thinking about for that. So here are some possible uses, and there must be many, many more, that you can have for a crop like this. I would like to emphasize again that I think it is a U.S. crop but we have to solve the politics first.

Dwight Miller

I feel like an outsider attending a 30-year reunion in which I had no part, but it certainly has been interesting these past three days. It appears that most of the work in this field has come to a standstill in that time. I wish to point out, however, that there are many other developments or new inventions coming along that certainly could contribute quite extensively to some of the problems that have been mentioned over the past three days. I am referring particularly to the question of water, and particularly the water at the time of planting or transplanting. At the Northern Regional Research Center in Peoria, of which I claim to be the Assistant Director, we have quite an extensive research program in new crops and also do a great deal of research on rubber chemicals. This is one reason that I am here today. I do want to mention something that we have rather recently developed that could play a very large role in not only this new

crop, but also other new crops that may be grown in the arid regions of the U.S. As part of our research program, we have developed a series of what we call starch graph polmers. We have a whole series of these materials and many of them have special uses in various fields from the paper industry to what-have-you. One of these which is the starch-polyacrylonitrile had such unusual properties and is attracting so much attention that one of the people happened to dub it super-slupper, because it seemed to grab onto and hold onto water so much. I'm sure that many of you may have heard of this material. We have a whole group of these. We now have advanced to where, in distilled water for example, some of these will hold 2,000 times their weight of water. I have picked up a piece of this at times and held a hunk of water. Really, it's 99.9 plus percent water, and yet it does not drip out of it at all. This has received a great deal of attention. At least 1500 companies have been in contact with us recently with interest in this material. Of course, the higher the salts and all, the smaller the amounts it can hold. It was classed as one of the top inventions of last year and in fact it was singled out further than that as one of the top six inventions in the U.S. in the last year. This material is under a national program now. You can imagine its biggest demand has been for a diaper material, because it will hold perhaps up to as high as 100 times its weight of urine and does not leak out in any way. You cannot even squeeze the water out of it if you pick it up by hand.

Today, both federal, state, and some of the other agencies are looking at this as a potential material for coating seeds before they are planted, or coating roots before they are planted. You put it in and need only the one watering. It is biodegradable and as far as we know is not toxic to plants. Of course, it will disappear in a matter of time. I just wanted to take the occasion to say that it's materials like this that could very well contribute to the development of such materials as jojoba, guayule, or many other materials in the arid regions. I welcome the opportunity to point out to you one of the recent developments of our Northern Regional Research Center which is part of ARS, USDA in Peoria, IL.

GUAYULE AND ITS INCORPORATION AS AN ECONOMIC ENTERPRISE BY AMERICAN INDIANS

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We are gathered at this Conference to discuss the various technological aspects of the guayule plant, its potential impact as a natural resource in the production of rubber, and in the future economic picture for many Southwestern Indian communities. Previous speakers have indicated that the development of the guayule plant will require a modern industrial approach for the planning, development, production and manufacture as a product for consumption.

From a socio-economic perspective guayule could offer a new way of life for Indian people, providing opportunity for leadership and management training, elements which are very essential in reaching the goal of self-determination and sufficiency. In dealing with the topic of Indian self-determination and the acceptance of guayule as a product for Indian production several important factors will be considered, factors which are in the field of institutional change and human behavior.

Essentially what we are talking about is not so much the acceptance of an agricultural product, but from a theoretical perspective the transfer of a technological innovation from one society to another. This does not mean that there would be difficulty transferring guayule as a native plant, but it does mean that for the acceptance of the technology to make guayule a saleable product requires a considerable knowledge, knowledge represented in a modern industrial society with many years of experience to transform raw products into finished goods for consumption.

The problem is therefore stated as: What is the process to incorporate into a tribal society a technological innovation developed by modern industrial society, requiring considerable training according to the scientific criteria of that society? In short, is it possible to transfer modern technological innovation to a tribal society that has not had the experience level to manage such an innovation? If so, what is the process of change and acceptance?

In my discussion of these questions, I will look at three examples of Indian business development, isolating crucial factors for the incorporation of external technological innovations, how these innovations were fused with Indian community activities and what changes occurred during the fusion and incorporation processes. Following this analysis I will offer suggestions for the transfer and acceptance of modern innovations from one society to another.

Prior to a discussion of these cases I want to acquaint you with a short history of tribal-federal relations, centering on major attempts by the government to raise the economic standards of American Indians. There is room for some criticism of federal attempts to improve the Indian economic picture in the past, but it's difficult to criticize current efforts to financially assist Indians. One need only look at PL 93-638, the Indian Self-Determination and Education Assistance Act, signed into law by President Ford this year. In this Act Congress severely criticizes Federal agencies for not assisting Indian communities in realizing the goal of self-determination and accepting responsibility for the management of tribal affairs. The Act sets out a mandate whereby Indian involvement shall become important in all future tribal-federal relationships, encouraging tribes to accept greater responsibility through contracting tribal services normally administered by federal agencies. This Act is a milestone for Indian opportunity, and could very well provide a training baseline for the development of management skills and employment of local residents in positions presently filled by non-Indians.

As exciting as is the possibility for Indian self-determination offered through PL 638 and other federal programs of Indian economic development potential as found in housing through HUD, small business and industrial development through EDA and SBA, there remains a conservative attitude in the all-out acceptance of these programs by the Indian people. The problem is not in the area of program availability, but in the area of acceptance, acceptance which becomes reserved through a century of inconsistent tribal-federal relationships.

At the beginning of tribal-federal relationships, Indian tribes were dealt with as independent nations, requiring treaties for the use of their lands by European immigrants. The first treaty between the United States and Indian nations was in 1794 recognizing the political sovereignty of these six tribal groups and their relationship with the United States.

As the pressure for land increased during the westward movement of European settlers, Indian tribes were either annihilated, assimilated, or pushed further westward. More organized tribal groups resisted with physical force or attempted to curb this encroachment through the court system as found in the Cherokee Nation versus the State of Georgia in 1931, and Samuel A. Worcester versus the State of Georgia, 1832, at which time the concept of a domestic dependent nation was defined, recognizing that the Cherokee tribe had territorial and sovereign rights as a tribal group. Anyone who has studied the history of that time knows that Chief Justice Marshall's decision was not respected when Andrew Jackson with federal troops forcibly removed the Cherokees from Georgia to Oklahoma in a march called the trail of tears where nearly 10,000 Indian people died.

For a period of time Indian affairs was managed by the War Department and in 1834 Congress established the Bureau of Indian Affairs to directly administer Indian affairs. Early federal policy attempted to negotiate Indian cooperation through the use of treaties, the violation of which was met with military force, consequently reducing a large portion of tribal resistance, setting aside Indian reservations to control hostilities and to protect Indians from extinction.

With Indian hostility controlled, the federal government established programs to assimilate Indians into the mainstream of American society, a policy which is reflected in an 1872 report to the Secretary of Interior:

> In our intercourse with Indians it must always be borne in mind that we are the most powerful party ... we ... claim the right to control the soil which they occupy, and assume that it is our duty to coerce them, if necessary, into the adoptation and practice of our habits and customs.

During the 1870's there were two important government activities aimed at Indian assimilation: the formulation of the boarding schools and the General Allotment Act of 1887 (Dawes Act). At this time boarding schools were operated with the following rationale described in a USBIA regulation code of 1884:

> Agents are expected to keep the (boarding) schools filled with Indian pupils, first by persuasion; if this fails, then by withholding rations or annuities or by such other means as may reach the desired end.

Historical documents reveal the process by which students were taken from their cultural setting, placed to strange environments with outsiders speaking a strange language, practicing unfamiliar customs. The recruiting of Indian students did not seek out tribal counsel or advice; it had a job to do: get the student civilized as soon as possible regardless of his previous experience or world view.

The Dawes Act of 1887 was passed under the basic assumption that what was right for the general population was also right for the Indian, i.e., every person should aspire to become a farmer, own a farm and raise a family in domestic tranquility. The Act allotted Indian lands held in trust to individual families, usually in 160-acre plots, the remainder of which was made available to non-Indian settlers. After a period of time the Indian obtained title to this land, a title subject to sale. The end result of this Act on Indian life-way is yet unclear; however, it is clear that nearly 50 million acres of Indian land had been transferred to non-Indian ownership, not including the fee patent land presently being sold by Indian owners. The idea of providing land for farmers was a good one, that is good for those wanting to be farmers; however, there were only a few tribes practicing farming in 1877!

Indian abuses through their relationships with federal policies and members of dominant society did not go unchallenged. Indian advocacy is represented in an Act of 1924 declaring Indians as American citizens, the Meriam Report of 1928 recommending major structural changes in Indian education, the Indian Reorganization Act of 1934, and the results of a task force report in 1960. The Act of 1934 was to:

> Conserve and develop Indian lands and resources; to extend to Indians the right to form business and other organizations; to establish a credit system for Indians; to grant certain rights of home rule to Indians; to provide for vocational education for Indians; and for other purposes.

Section 9 of this Act authorized $250,000 in any fiscal year "in defraying the expenses of organizing Indian chartered corporations or other organizations created under this Act," and Section 10 appropriated $10 million as a revolving fund for promoting tribal economic development.

Indian economic development proceeded under the direction of the BIA, and tribal councils were organized and chartered under the provisions of this Act. Some tribes were so successful with economic development that Congress in 1953 passed House Concurrent Resolution 108 (PL 587) which provided for the termination of federal services to the Klamath and Menominee tribes. PL 280 was also passed in 1953, authorizing states to assume responsibility for law and order in Indian areas.

Each of these Congressional Acts was based upon the subtle policy of Indian assimilation and the withdrawal of federal services, assuming that these tribes are self-sufficient and willing to become part of America's social mainstream.

It is interesting to point out the great difference between the ideal of Indian assimilation as a human right and the federal policies inhibiting this process, i.e., the establishment of Indian reservations and attempts to destroy core tribal values facilitating isolation and resistance, discouraging voluntary assimilation. It must be remembered that assimilation also requires a willingness on the part of people to accept others as members of their own group, a process that has rarely taken place between Indians and surrounding non-Indian communities. The sting of social rejection and the fear of termination of federal services are two major barriers to Indian assimilation as part of the so-called American mainstream.

However, despite inconsistencies in federal policies for Indian economic development and assimilation, there are rising numbers of examples within Indian communities revealing Indian efforts towards self-sufficiency and developing small businesses. These developments are occurring within the cultural frameworks of tribal society within their own time perspectives, supported through funds sponsored by the dominant society. Some of these enterprises are undertaken by Indian individuals who provide their own impetus and capital as is found in the case of Edward Kisto, a Papago, who established a landscaping service in 1971. Mr. Kisto's Papago employees work on projects contracted by him both on and off the reservation. This firm uses natural products such as ocotillo cactus and saguaro ribs in fence construction and landscaping. He never exceeds the limits of his own capital nor does he accept more jobs than his workers can manage. The concept of profit making is used only for creating capital for paying wages and gradual business expansion.

Other Indian enterprises are found in family organizations which operate as part of a community function. Such an operation is found with Hopi Crafts at Oraibi, Arizona. Started in 1961 by Wayne and Emory Sekaquaptewa and sponsored by a small federal loan, this business has grown from an operation of two brothers into one employing 15 full-time workers, producing silver crafts of high quality known throughout the United States. The expansion of this business has come from within the business itself and federal interference has been resisted.

Hopi Crafts has its own training program for Hopi youth, its own sales shop, and its own marketing outlet. The decision-making process for the operation of Hopi Crafts comes from the Hopi mind, and its operation respectfully considers the ceremonial calendars of Hopi life and the needs of the Indian community. Many of its workers hold responsible ceremonial positions in nearby communities and personnel matters are solved according to Hopi custom. This operation is not motivated by profit motive and refuses to exploit its employees as a commodity of production. Fellow employees are in many cases blood or clan relatives and the monetary returns are shared with the community through employment and in business expansion.

The acceptance of technological innovation in the production of silver never exceeds the comprehension of native craftsmen and production is geared to provide a comfortable life wherein each craftsman sees the product from conception to completion.

The last case is with the San Carlos Apache Jojoba Cooperative. This cooperative was organized by Apaches with assistance from the University of Arizona and funds from several federal sources. Starting in 1972 with a grant from OEO to fund harvesting of the jojoba seeds, some 80,000 pounds were gathered by Apache families, thereby forming the baseline for oil extraction, chemical experimentation and raw material to involve and interest industrial firms. The acceptance of jojoba as an Apache industry was more easily facilitated since it is a plant native to the area, used and named by them for medicinal purposes, and a form of ready cash to family groups on a seasonal basis. The real test came when Mr. Anderson helped organize the Cooperative requiring Apache management and commitment to a long-range program. The organization of the Association followed the Apache pattern of careful review of important factors according to their time schedule of acceptance. No high pressure selling could be used nor could the concept of profit making be used to implement this program. More importantly, planning wherein all members of the community could benefit with the decision-making process remaining in the hands of Apache people is identified as an important criteria for acceptance of the jojoba program. Profits were not seen as profit for profit sake, but as the means for group survival, providing employment for Indian people. Apache talent was expressed in the development of candles bearing unique Apache artwork. Creativity according to the Apache culture became an important element in the development of an industry supported by the Apache community.

It's too early to determine the success of the Apache jojoba industry at San Carlos. However, there have been some important developments which are crucial to Apache acceptance of jojoba as a technological innovation. Important to this acceptance is the formation of the association by the Apache people themselves according to Apache criteria of time and the acceptance of responsibility. The acceptance of responsibility was a group process requiring the support of families involved with the harvesting, the five-member board of directors from the Apache community, the 1500 Apaches who have donated one dollar to become a member of the association, and the artists who have dedicated their talents in the creation of a native conceived industry represented in candle production.

In the analysis of these case histories taken from the Apache, Hopi, and Papago Reservations, several things can be said concerning Indian acceptance of outside innovations as part of their economic development. Firstly, innovations are only accepted if they represent no great alteration of existing cultural frameworks, and the incorporation of innovation must conform to existing time schedules which are compatible with the functions of the community. Secondly, the acceptance of innovation must involve the decision making and imagination of community members who are involved in the change process. Changes must bear cultural impressions during the transfer process; one cannot expect a society to incorporate innovations without modification. Finally there must be time allowances made for the development of managerial skills in the acceptance of responsibility for the development of new innovations by tribal people. The greater the technical skills required to manage new innovations, then, greater must be time for institutional changes within the social system to effectively manage the innovation.

We have seen through this presentation that tribal-federal relationships, despite their great inconsistencies and their attempts to assimilate Indians away from their tribal ways, have not completely eradicated their ability to function as tribal people in the development of new industries. However, it was shown that the acceptance of new innovation cannot exceed the cultural limitation of acceptance, levels of which vary from tribe to tribe.

Therefore, tribal acceptance of innovation thus far has been a gradual process, a process which must be time tested and proven workable by tribal cultural standards. I seriously doubt that innovations requiring vast technical knowledge for development which could threaten existing cultural foundations will find ready acceptance by Indian communities, especially if one expects these communities to incorporate these innovations as part of its society's function.

However, it is possible to introduce innovation gradually, providing opportunity for leadership experience among tribal peoples who would eventually accept managerial responsibility.

It is in the area of leadership development at a pace acceptable to the Indian community that guayule or any other technological innovation offers its greatest economic potential to Indian communities. It is therefore important for Indian acceptance that the introduction of new innovations to Indian communities seriously recognize Indian values, time perception, and social structure.

Concluding Remarks

Noel Vietmeyer
National Academy of Sciences

As a younger scientist I must say how impressed I am with the Emergency Rubber Project. What a wonderful project it was and what a tragedy it hasn't been given greater credit!

It existed only for three and a half years but it solved dozens of technical problems, produced billions of guayule seedlings as well as three million pounds of rubber for the war effort, and a further 21 million pounds in the bushes that, in 1946, were destroyed unharvested.

The success of this Conference has been due to the dedicated effort expended by the thousands of ERP scientists, technicians and workers. What we've learned here is largely based on their work.

Some of the important points we've learned are:

1. That guayule was not abandoned for any technical reason inherent in the rubber. This can be seen clearly from the Conference discussions. Rather, the abandonment was due to reasons of politics and prejudice which have never been published or explained explicitly. Our guayule historian, Dr. Droze, could perhaps ferret them out from the archives in Washington.

2. That probably more is known about guayule (900 published papers and hundreds of cubic feet of files in the archives in Washington) than any other crop that is not now in production. Good manuals for its handling and production are available.

3. That guayule production is readily mechanized (and standard equipment, only slightly modified, can be used). This is important for countries like the United States.

4. That although irrigation may be needed, the 16-18 inches of total moisture that guayule requires is far less than conventional crops need. Here in the water-scarce Southwest, this may become very important.

5. That guayule yields can't compare with modern *Hevea* rubber yields but there are tantalizing tidbits of information that give hope that the situation may rapidly change. Guayule physiology is ideally set up for genetic improvement, and the variability exists to allow us to exploit it. Dr. Benedict mentioned one experimental plot that produced an increase of over 100 lbs. of rubber per acre per month during a period of almost two years.

6. That guayule's fertilizer requirements are not great. Today, that is a very important advantage for a crop plant, and with increasing energy prices it's going to become more important in the future.

7. That guayule can be affected by some fungi and bacteria. Yet they are the common controllable microorganisms that infect conventional crops such as lettuce and cotton. We also learned that no viral diseases (which are particularly difficult to control) are known, and that guayule also resists root knot nematodes, another serious pest. Nothing was mentioned about insect pests--I believe that's because they are not serious.

8. That guayule's by-products may become important--more important than the rubber, some speakers have said. Wood pulp is a valuable commodity today; so are hard waxes, and guayule cuticle wax has a higher melting point than carnauba, the very "king" of waxes. Some of the resin ingredients may, with further study, also prove to have some commercial value.

In addition I'd like to suggest consideration of one more by-product: guayule seed. Guayule is a prolific seeder, and the seed is readily removed. Could the plants be used as an oilseed crop? If this can be done to profit the farmer more than his harvesting costs, it could make guayule growing far more attractive and provide income and employment during the otherwise lean years before the rubber reaches harvestable quantities.

Dr. Federer suggested two more special situations that could mitigate concerns over the long time between harvests. One is intercropping useful plants between the rows of young guayule and the other is the use of guayule to stabilize soil and prevent erosion. In this latter case guayule could still serve as a rubber source or as a standing stockpile of rubber for strategic emergencies.

Since the ERP days, technology has made miraculous advances. Analyses that 30 years ago would have taken months can now be performed in minutes. Indeed, today we can gain insights into guayule rubber's molecular structure that were undreamed of even 10 years ago. Luckily for all of us guayuleros, U.S. Department of Agriculture researchers, 20 years ago, carefully preserved one block of deresinated guayule rubber. A month ago, Bill Miller, Irvin Feustal and I found it in a federal archive in Washington, D.C., still well preserved. Samples of this block, analyzed courtesy of Goodyear Tire and Rubber Company, have demonstrated the remarkably high qualities described to the Conference by Mr. Pierson. These are confirmed by Dr. Campos's results and we can now say that <u>guayule rubber has properties virtually identical with those of Hevea rubber</u>.

In molecular structure, in average molecular weight, in glass transition temperature, in thermal stability, in thermal oxidation stability, in heat capacity and in tensile strength, guayule rubber is essentially identical with <u>Hevea</u> rubber. Dr. Campos and his colleagues from Mexico deserve all our recognition for the work they've done in this area. It has brought a quantum leap to our knowledge of guayule rubber. With wonderful foresight, the Mexican government is backing their guayule program with a well-funded, well-planned, pilot rubber production program. I'm terribly impressed that they're approaching it by applying the very latest in scientific and technical knowledge. Their method of handling the rubber in solution gives them great power to protect the rubber against oxygen and ozone, to remove impurities, to modify the rubber chemically: it gives them great control over homogeneity, and over quality in general. Perhaps they will develop SGR--Standard Guayule Rubber. It was SMR--Standard Malaysian Rubber--that brought uniform and guaranteed quality to <u>Hevea</u> rubber. It was a great advance in the marketing of <u>Hevea</u> rubber; in guayule it would be a giant step into modern times.

When guayule was abandoned 30 years ago, the times were wrong. But we are now in the midst of a vast change in the world's appreciation for plant-derived resources. We can thank the OPEC cartel for that....together with a growing awareness that in a few more decades, the world will be out of petroleum. This change favors reconsideration of guayule and other events make it even more urgent:

1. OPEC revives memories of the British/Dutch rubber cartels in the 1920's and 1930's that completely controlled the amount of rubber the U.S. could purchase.

2. The skyrocketing price of petroleum that is increasing the price of synthetic polyisoprene rubber, guayule's man-made competitor.

3. The burgeoning population that is forcing us to utilize marginal lands, the kind where guayule will grow.

4. The desperate plight of Indians, on impoverished arid reservations in the Southwest who need crops that can be farmed in their parched soils.

Perhaps none of these factors alone is enough to justify renewed guayule production. Together, however, they make a strong case for reviving guayule research, development and testing.

During the Conference it became apparent that we've barely scratched the surface in most research areas relevant to guayule exploitation:

1. in breeding and genetics
2. in extraction technology
3. in guayule rubber technology
4. in understanding the value of the by-products

Much remains to be done and it will be exciting research. Once the word gets out, I think that many researchers worldwide will want to exercise their skills in these areas. As Dr. Bonner said, "There's a lot that can be done with rubber plants and there remains a lot to be done with guayule."

Today we don't have a wartime emergency; we don't need a crash program. We have time for contemplating, for trials, for testing, for comparing different approaches and techniques. The tools at our command are vast, and much greater than those available to the previous guayule projects.

But the thousands of researchers and technicians who know how to use the tools and techniques are unaware that guayule needs them. We, the participants in this Conference, have seen the light and can point out the darkness that needs illumination. Let's go from here and inoculate new generations with guayule fever. The heat and stress that that generates may be enough to bring guayule bouncing back.

Let this not be the end of the cooperative spirit generated here. Let's try to keep it going. Won't someone take up the challenge and produce a guayule newsletter to keep us all in contact? It's worked wonderfully for jojoba. Also, let's develop a roster with the names and addresses of all the guayuleros we can find, so that we can get the Conference's message to them and we can give them a chance to add their voices to ours. To the roster should be added the guayulero's affiliation with the previous programs and his area of expertise. I think that in the near future many scientists will need their advice. This could be crucial for getting modern guayule research off the ground in the most efficient way and with the fewest mistakes.

I'd particularly recommend that a joint US/Mexican guayule cooperative effort be instituted. It's clear that it would be mutually beneficial. We have much to learn from each other.

In summary, I'd say that the spirit of the meeting is cautiously positive. I don't think that anyone is going to charge out into the desert and pour their money into guayule plantations. Nevertheless, there's a feeling that with good funding, good research, and good will from industry and government, that guayule could become a national materials resource for the United States, for Mexico, for Israel, and I suspect for other countries too.

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