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NONFERROUS METALS

20 November 1950

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RESTRICTED

Dr. James Boyd was born in Kanowa, Western Australia, in 1904. He was educated in both England and the United States, receiving a B.S. degree in engineering and economics from the California Institute of Technology in 1927. He was awarded an M.S. by the Colorado School of Mines in geophysics in 1932, and received his Sc.D. from the same school in geology in 1934. After serving two years (1927-1929) as field engineer with the Radiore Company, Dr. Boyd was engaged as instructor by the Colorado School of Mines. In 1935 he was appointed assistant professor, a post which he held until 1939 when he was named associate professor. During World War II, he served in both this country and Europe, attaining the rank of colonel. In 1941-1942 he was chief of the Metals and Materials Section, Commodities Branch, Resources Division, Headquarters Services of Supply. In 1943-1944 he served in the Office of the Director of Material, Headquarters Army Service Forces in Washington, and was the U.S. Army representative on Program Adjustment of the War Production Board. In 1945 before VE-day, Colonel Boyd was sent to Europe to direct the activities of the Production Control Agency under G-4 of the Supreme Headquarters of the Allied Expeditionary Forces and also the Industry Division of the Office of Military Government. The latter organization, functioning under General Clay, Military Governor of the American zone of occupation in Germany, helped to reorganize and reestablish German mines, mills, plants, and other industries. Colonel Boyd remained in Germany until the summer of 1946, returning then to the Colorado School of Mines. In recognition of his wartime services, he received the Legion of Merit award, with oak leaf cluster. In August 1947 Dr. Boyd was made Director of the Bureau of Mines, his present position.

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COLONEL BERKELEY: During the past several weeks the course on natural resources has been presented through a series of lectures, seminars, and exhibits. As you will recall, the lectures covered iron and steel materials, energy resources, petroleum and natural gas, and the stockpiling program. The class seminars considered agricultural resources and rubber. The exhibits covered a wide range of natural resources. These activities, it is hoped, have provided a wider understanding and a fuller appreciation of the role of natural resources in both war and peace. This morning the subject of our lecture covers the one remaining broad group of natural resources which has not as yet been considered, that is, the nonferrous metals. These metals include copper, lead, and zinc; the lightweights aluminum and magnesium; and the new middleweight champion titanium, which has been introduced to you by Colonel Hickey. These and other metals of this group have been receiving front-page attention in our daily newspapers with increasing frequency. This attention stems from the fact that they have wide and numerous applications in military supplies and equipment.

You have all read the biography of our speaker. To that biography I would like to add two postscripts. In the first place, the Research and Development Board a few weeks ago held a conference of representatives of government and industry to consider the present status and future application of titanium. Of all the people in and out of government, our speaker was asked to serve as chairman for this conference. Secondly, he has most recently been designated Executive Administrator for the Defense Minerals Administration, which has been established under the provisions of the Defense Production Act of 1950. The purpose of this organization, among others, is to assist in the expansion of the minerals industry. As you are aware, our speaker wears many hats. He is the Director of the Bureau of Mines, the Deputy Administrator of the Defense Minerals Administration, a doctor of science in the field of geology and mining, and was a colonel in the United States Army during World War II. It is a pleasure to welcome to this platform Dr. James Boyd.

DR. BOYD: Here at the National War College on 1 March 1950, I discussed the influence of raw materials upon the problems of strategic planning. At that time, although the United States was looking ahead to a possible future conflict, few realized that before the summer was over American troops would once again be engaged in battle on foreign soil. In my earlier lecture I attempted to explain how the supply of raw materials, specifically of mineral raw materials, influences the conduct of war; today I am going to present a somewhat different aspect of the same problem--the supply of nonferrous metals.

First, what are nonferrous metals? It is probably easier to define this particular metal classification by indicating what they are not. This may seem an odd procedure; but metal and mineral classification methods are far from perfect, and it is necessary to remember that one metal may have applications in a number of fields. The ferrous metals, which I shall not discuss in this lecture, are those used in making iron and steel. In this classification are chromium, manganese, cobalt, vanadium, tungsten, titanium, nickel, molybdenum, and, of course, iron and steel. Under certain specialized conditions, tantalum, columbium, boron, and even copper could be included. In fact, to be absolutely accurate, all metals that go into alloys for iron and steel should be listed, and it is obvious to those familiar with modern metallurgical practice that the list would be a long one. However, for the sake of this discussion I do not intend to split hairs, and in considering nonferrous metals I shall discuss the general group that includes copper, lead, zinc, mercury, tin, cadmium, antimony, bismuth, the light metals (aluminum, magnesium, and titanium), and a few other metallic commodities that enter the picture. First, I shall explain the distinction between the so-called "base metals" and the "precious metals." The term "base metals" is predicated fundamentally upon the ancient concept that tarnishable metals were base and those that were not were noble. Thus, gold, silver, and platinum would be classified as noble metals, while copper, lead, and zinc would be considered base metals.

Reviewing the problems associated with nonferrous metals the problem of supply will not be discussed on a commodity basis. To handle this adequately would take several hours; furthermore, it might be impracticable to review the subject effectively in one lecture. Some general problems will be considered as they apply to the nonferrous metals in order to present a panorama of the current domestic situation. However, before these problems are stated, the fundamentals of mining and mineral extraction will be outlined, because they influence the supply of nonferrous essential raw materials.

Unfortunately, the geologic processes responsible for the deposition of ore and the establishment of ore deposits have been most unsystematic. Nonferrous metal deposits are scattered over all quarters of the globe, some in the midst of dense jungles; some along the tops of inaccessible mountains; some in waterless deserts; some under arctic tundras; and some on isolated islands in the middle of the Pacific Ocean. No one nation and no one continent is favored exclusively--the world's ore deposits occur on the six continents and border the seven seas, irrespective of political or national boundaries. This helter-skelter arrangement has motivated wars and altered international boundaries.

The Development of an Ore Deposit

Where an ore deposit has been discovered and it is evident that the ground contains enough mineral to justify further investigation, the first task for a geologist or a mining engineer is to determine the workable reserves. He must attempt to determine not only the quantity of ore available but also its grade and sooner or later someone must analyze the ore from a metallurgical standpoint. Fortunately, the owners or operators of an ore deposit are in a favorable position with respect to sales--they are not introducing a new product that must be advertised; the market for copper, lead, zinc, and other metals is long-established and depends only upon industrial demands, not the whims of the public. However, the question invariably arises, "Is the deposit workable?" By this is meant, "Is it possible to extract the ore economically?"

Before 1900 it had been uneconomic to mine the extensive low-grade copper deposits that furnish most of our domestically produced supply today. Mechanization of mining and metallurgical progress have changed the mountains of rock to ore deposits. Formerly, copper ores had to contain several percent of the red metal, but since 1943 the average copper ore mined in the United States has contained less than 1 percent.

Assuming that a mineral deposit has been located and that it is practical to extract the metal from the ores, the feasibility of mining must also be considered. The factors that affect the economic workability of a mine are varied and may include such questions as whether or not the mine can be operated by open pits or through underground workings. Power supply must be available and it may be necessary to install pumps for eliminating water from the lower levels. Obviously, the methods and costs of transporting the ore or concentrate enter into the calculations, as well as employee--housing and machinery supply.

All of this preliminary work requires tremendous capital. A generation or more ago a prospector could go into a field with rather sketchy equipment and develop a small property with comparatively little capital--today this is almost impossible. In the early days of pioneering in the Western States, when prospectors were searching primarily for precious metals, small-tonnage operation was feasible and practical. Today metal production is thought of in terms of huge tonnages; this applies particularly to the nonferrous metals. Because mining is inherently a risky enterprise, investors are not interested unless there is a chance for good return on capital investment. What this return should be is of course subject to considerable discussion and interpretation. No two economists will agree on this particular point.

Time Factor is All-Important

Moreover, it is well to remember that these preliminaries take time. Mines cannot be opened or closed merely by turning a spigot or throwing a switch. The development of a successful tonnage operation is not a matter of weeks or months but often of years. It took nearly 20 years to develop one of our largest copper producers in the Southwest. Because every ore deposit differs inherently from every other one, the development of any specific mine or ore body may involve investigation of some highly specialized metallurgical or chemical process, which may take many months or even years.

To refer again to capital requirements, it must be remembered that mining occupies a unique position in that it is the one industry that is perpetually depleting its capital resources; unlike farming, mining is a one-crop project. Consequently, both in financing and in taxation, special allowance must be made to replace capital out of what appears to the uniformed to be net return. In addition, money invested in mining is often tied up for many years; consequently, when mines actually begin to produce, an investor logically expects a large proportionate return on his money, which may have been unproductive for 10, 15, or 20 years since his original investment.

The Seven Specific Problems of Nonferrous Metals

Rather than present a discussion of nonferrous metals by commodity groupings or as individual metals, what might be called the seven major problems of the nonferrous metals, industry will be reviewed in terms of generalities rather than specific technical or economic problems. In brief, the seven specific problems under discussion can be listed as follows:

1. The problem of diminishing domestic supply--the specific examples being copper, lead, and zinc.

2. The problem of meeting requirements for the big three.

3. Where sources of the metal lie abroad--the case of tin.

4. Where power is a primary factor in production--the light metals.

5. Where a metal is only a byproduct--as with cadmium and bismuth.

6. Where price governs new production--the case of mercury.

7. Where sale of a byproduct has provided the needed stimulus--the place of silver.

It is important to remember that virtually every metal presents problems of its own. Thus, the economics and metallurgy of copper differ considerably from those of aluminum. The problems of quicksilver and those of lead and zinc show very little similarity. In many instances our mines produce more than one metal. As many of you know, lead and zinc usually are associated in the same ores, and in some instances copper or silver are present as well.

The Problem of Diminishing Domestic Supply

The problem of diminishing supply is well illustrated by the metal copper. Copper is possibly one of our most important nonferrous metals. Without copper the electrical industry would be very different; moreover, copper is required by the brass and other alloying industries. Needless to say, without copper it would be extremely difficult for our technologic age to function.

From 1935 to 1939 domestic mine production of copper approximated 625,000 tons a year. During this period the United States consumed an average of approximately 583,000 tons a year, imported 263,000 tons a year, and exported about the same quantity--imports were largely copper that came into this country in bond for processing. Look at the situation today. The United States now produces more than in the 1935-1939 period, and in 1949 production jumped to 753,000 tons. However, the consumption figure was 1,072,000 tons; imports were 550,000 tons, exports 138,000 tons, and net imports 415,000 tons. That figure, 415,000 tons, represents the copper deficit for 1949; last year this deficit was 66 percent of the 1935-1939 average mine production figure, which, as previously stated, was 625,000 tons. Putting this in another way, copper imports today are about two-thirds of the previous production during the five years 1935-1939. This statement should be food for serious thought.

Next consider another versatile metal, lead--an industrial metal almost as important as copper. Lead is used in protective paints as red lead and white lead--oxides of the metal that are extremely valuable for protecting structural steel, especially when exposed to the corrosive action of salt water. It is lead paint that protects large suspension bridges spanning the harbors of great ocean ports. Lead is also the most important ingredient in storage batteries; lead imparts antiknock qualities to gasoline; lead cables make it possible for telephone lines and other electric installations to function

underground. The demands on lead are many; in addition to the uses already mentioned, it is also important for alloying metals, solders, type metals, calking, ammunition, building, and shielding. However, lead that is consumed in storage batteries, cable coverings, and certain other uses has scrap value and in many instances can be recovered, wheras lead that goes into white lead, red lead, and litharge paints or tetraethyl lead cannot, of course, be recovered and is lost forever.

Let us review the situation as to lead production and consumption. Production here means mine production, and consumption means new lead and not scrap. During that same period from 1935 to 1939, the average annual production of lead in the United States was 391,000 tons and consumption 381,000 tons--just 10,000 less. Imports totaled 48,000 tons and exports 33,000 tons annually; net imports were thus 15,000 tons. In 1949 the United States produced 410,000 tons of lead but consumed 593,000 tons. Imports were 384,000 tons and exports none. Obviously, some of this lead went into the national strategic stockpile, but aside from that, it is evident that this country now imports as much lead as it produced from 1935 to 1939.

The last of these three important nonferrous metals is zinc--one might call copper, lead, and zinc the traditional triumvirate of the nonferrous base-metal world. As with copper and lead, the uses of zinc are legion. Its most important single use is for galvanizing, the application of a protective coating of zinc to prevent the oxidation of iron and steel. Moreover, it has an important place in the alloying industry and of course is used in bronze and brass. Zinc paints are also in demand, and the zinc-casting industry is a large one--many automobile carburetors are made of zinc, and all of you can recall zinc castings as used in household appliances, and so on.

The situation with respect to zinc during the 1935-1939 period, compared with that for copper and lead, is as follows: The average annual United States mines output was 564,000 tons and consumption approximately 510,000 tons; imports totaled about 34,000 tons, and exports were relatively small during this period. In 1949 the situation changed, and very noticeably. Mine production was 593,000 tons, somewhat higher than the annual average for 1935-1939; consumption totaled 712,000 tons and net imports 309,000 tons. This discussion will ignore consumption of scrap and the small quantity of zinc exported, because the latter was smelted in this country from foreign ores for the foreign market. The outstanding feature is, however, that domestic requirements have increased by leaps and bounds; approximately 200,000 tons more zinc is needed than during that 1935-1939 period, but domestic production has not been stepped up in proportion to these new demands. Imports now represent somewhat over 50 percent in quantity of the mine output from 1935-1939.

The Problem of Meeting Requirements for the Big Three

The question will invariably be asked, "How did the United States get into this situation, and what is the reason for the present deficit of these three important key metals?" The reasons are many and varied; but, primarily, the metal industry faces the problem of supplying an expanding economy, plus operating against a fixed or comparatively fixed reserve of mineral commodity in these three fields. This expanding economy has been caused by a number of factors, including an increase in population, the requirements of war, and the demands of a highly mechanized economy that continues to grow irrespective of the limitations of metal and mineral resources. Fortunately, in many instances impending shortages and deficits have been overcome through technology that either made lower-grade deposits workable or pointed to the way to the utilization of substitute metals available from more aboundant resources. For example, in many instances aluminum sheet has replaced steel sheet galvanized with zinc; many farmers are now finding aluminum sheet roofing just as effective as galvanized roofing. Aluminum paint has also be substituted for red lead paint as a covering for structural steel, and in some instances is nearly as satisfactory.

The time undoubtedly has come with respect to these three important metals when imports should be stepped up sharply. The few figures presented make this conclusion inescapable, and of course from a military standpoint this poses a very important logistic problem--maintaining a long supply line during a national emergency. Fortunately, friendly neighbors occupy the country's northern and southern boundaries. Some copper, lead, and zinc can be obtained from Canada, but it must be remembered that Canada's requirements are also expanding. Mexico and other Latin American countries can also supply large quantities of nonferrous metals. It is of utmost importance that copper from Chile continue to be available and every effort should be made to see that nothing inhibits the flow of ores and metals from other Latin American sources.

The Metals We Must Import

The third of the seven problems posed involves metallic and nonmetallic commodities whose source materials are unavailable within the territorial boundaries of the United States or its possessions. The outstanding nonferrous metal in this category is tin. As reported by the International Tin Study Group and the Bureau of Mines, in 1949 the world produced somewhat over 161,000 long tons of tin. In that year a major portion came from Malaya--a total of 54,910 tons. Bolivia furnished 34,123 long tons and the third largest producer was Indonesia, with 28,965 tons. The Belgian Congo tin production was 13,593 long tons, and the balance of the world output came from such scattered areas as Nigeria, Australia, China, Portugal, the United Kingdom, Uganda,

and others. You will note that no tin is recorded from the United States, and although one mine in Colorado does extract some tin as a byproduct from its concentrates, production is only around one ton a month. The United States consumes approximately one-half of the world's tin production, in 1949 using 47,163 long tons of primary tin; 29,895 tons in the production of tin plate.

Tin is now almost an irreplaceable metal. It is used for tin plate, solders, in the brass industry, bronze, Babbitt metal, type-metal, and tinning. In 1949 United States imports comprised 38,358 long tons of tin in concentrate and 60,322 long tons of bars, pigs, blocks, and so on; imports therefore totaled 98,680 tons. It is necessary to remember that very nearly 60 percent of the world's tin comes from the Far East--Burma, Malaya, Thailand, and Indonesia. These figures indicate this country's dependence upon foreign sources for tin; and, although substitutes for this important metal in many instances may ultimately be found, at present it is indispensable, and every effort must be made to insure a continuing supply in the future. Furthermore, the United States must insure a continuous supply from Bolivia; in view of the current situation in the Far East, this becomes doubly important.

The question is frequently asked, "Is there any possibility of improving the domestic tin production situation?" Unfortunately, the answer must be "No." The United States and its territorial possessions simply are not endowed with commercial grade tin ore. Despite the concerted efforts of industry and government agencies during recent years, there is little indication that enough tin ore will ever be found to satisfy even a small proportion of the national requirement. Although there are some small tin deposits in South Dakota, Colorado, New Mexico, California, and other western states, none of them have, upon investigation, warranted development. Probably America will continue to rely upon foreign sources for this metal and will have to search more assiduously for substitutes as time goes on.

Tin is probably the most important single nonferrous metal that must be procured from foreign sources. This country also lacks nickel, here classified as a ferrous metal even though in some instances it has nonferrous uses. A number of nonmetallic minerals must also be imported, including quartz crystals, strategic grades of mica, high grades of asbestos, and industrial diamonds.

Where Power is a Primary Factor in Production--the Light Metals

Although electric power plays an important role in the metal industries, the power requirements of the light metals industry are proportionately more important because production of light metals depends entirely upon electrolytic processes. Therefore the quantity of

aluminum and magnesium--titanium might be added at this point--that can be produced is a direct function of the electric power available. This poses the fourth of the seven problems--production of minerals predicated upon the availability of electric power.

Take a brief bird's-eye view of the aluminum industry. In 1949 consumer demand for primary aluminum far exceeded the productive capacity of the industry during the early part of the year. A huge backlog of orders for aluminum maintained a relatively firm market throughout most of the first quarter of the year. Thereafter, as with most other metals, demand fell rapidly, producers' stocks expanded, and metal shortages disappeared. It should be noted, however, that the beginning of the downward spiral in aluminum demand coincided in 1949 with abandonment of plans for a 70-group Air Force. Obviously, this situation has changed today with the increase in military orders.

The uses of aluminum are many and varied. However, a pronounced shift has developed in the application of aluminum during recent years, especially within the transportation field. Much of this has resulted from the expanded use of aluminum in military aircraft procurement programs. Although motor vehicles previously used about two-thirds of the aluminum consumed by transportation industries, it is estimated that over half of the 1949 total for transportation was used in aircraft. During 1949 many new aluminum products were introduced, including forged aluminum truck and trailer wheels and variations of extruded floor systems and other parts for these vehicles. Manufacturers have found that motor transport operators demand weight saving, reduced maintenance, and other advantages accruing from the use of aluminum. More aluminum was also consumed in 1949 in railroad tank cars than in any other year, and new designs in certain passenger units have utilized large quantities. In 1949 the United States consumed more than 816,000 short tons of metallic aluminum. Of the total, roughly 45,000 tons were recovered from old scrap and 136,000 tons from scrap generated and shipped from consuming plants. Averaging the annual national consumption for 1940-1944 (which of course includes part of World War II) gives a figure of 738,000 tons, including 37,000 tons recovered from old scrap and 167,000 tons from plant scrap.

Aluminum is derived from the mineral bauxite; and, except for relatively low-grade ores still available in Arkansas, the United States must import huge tonnages of bauxite for domestic aluminum production. By far the largest portion comes from Surinam or Netherlands Guiana on the northeastern coast of South America; bauxite ores are also imported from Indonesia and to a lesser degree from British Guiana, which is also the main source of supply for the aluminum of Canada. Here again the major source of an important metal lies overseas, and once more bobs up the problem of maintaining a supply line in wartime.

As previously noted, the production of aluminum is predicated largely upon electric power; where such power is available from relatively cheap hydroelectric installations, it is obviously advantageous to have plants nearby. Since the conclusion of World War II, Canada has produced approximately one-fourth of the world's primary aluminum ingot. Low-cost hydroelectric power has enabled the Aluminum Company of Canada, the only Canadian producer, to maintain a position as the leading supplier of metal on the international market, particularly for consumption in Great Britain and the United States. All five of its reduction plants, including the largest in the world at Arvida in the Saguenay Valley, are in the Province of Quebec. Here in the United States where aluminum plants are functioning at the present, they are close to available inexpensive power, usually hydroelectric. It is well to remember that every pound of aluminum produced takes nearly 10 kilowatt-hours of electrical energy. This figure cannot be greatly reduced so long as aluminum production continues. Thus expansion of domestic production facilities and location of aluminum plants for wartime purposes will depend not only upon the possibility of adequate protection in case of bombing, but also upon accessibility to cheap hydroelectric power.

The second light metal listed is in a somewhat similar category. Magnesium, like aluminum, depends upon electric power for production and refining; but, unlike aluminum, the sources of magnesium are boundless. At present, production and fabrication capacity greatly exceeds current needs; and, since magnesium is extracted from sea water, as well as from magnesium-bearing rocks, which occur in tremendous quantity, especially in the Western States, sources are assured for generations to come. Unfortunately, the production of magnesium from sea water is expensive. When magnesium is extracted from magnesium chloride using the electrolysis method, the plant facilities cost on a ton-year basis is approximately $1,650. If, on the other hand, magnesium carbonate is reduced with ferrosilicon, the figure drops from $1,650 per ton to $720. Unfortunately, however, chrome-nickel steels in quantity are required for retort purposes in this process. The present output of magnesium is approximately 18,000 short tons a year.

Undoubtedly, magnesium metal has a great future. The source of supply is infinite; as time goes on, magnesium will undoubtedly replace other metals in many fields. A magnesium engine block weighs less than half that of a block cast from iron--it is also lighter than an aluminum block. The density of magnesium is 1.74, while that of iron is 7.89, and that of aluminum is 3.70. Unfortunately, magnesium is not an easy metal to work; however, as metallurgical practices improve, the day undoubtedly will come when magnesium will be fabricated as easily as copper, iron, or other metals in common use.

The final metal in this group, titanium, is rather a newcomer. Although the element has been known for many years, it was not until recently that researches disclosed its properties and its many advantages. Titanium has a density of 4.54--remember that iron has a density of 7.89. However, titanium has a higher melting point; and, where iron melts at 1,539° C., titanium melts at 1,725° C. If this melting point is compared with that of the austenitic stainless steels, it is found that these steels melt at 1,535° C. against 1,725° C. for titanium. Furthermore, titanium resists corrosion, and the titanium oxides have been used for many years in white pigments, largely replacing white lead.

It is obvious that titanium should have important military applications in the future. Its strength, lightness, ability to resist corrosion, and high-melting point all indicate that it can replace iron and steel to advantage in many future weapons. If nickel shortages are imminent, titanium may be substituted for certain nickel steels. Unfortunately, once again the power problem arises. Titanium at present requires magnesium in its processing; in addition, the extraction of titanium also consumes tremendous quantities of power. It is now an expensive metal; but, as time goes on, and the technology of titanium extraction and metallurgy improves, it is reasonable to hope that the price will drop. Today titanium is at about the same point that aluminum was in 1890. It is well to remember that at the St. Louis World's Fair an ingot of aluminum displayed in a glass case had to be watched by special guards. Aluminum was a precious metal 60 or more years ago and as late as 1917 was termed a minor metal. If the history of aluminum is repeated, it is reasonable to forecast that titanium will become cheaper and have a wider application as time goes on.

In brief, this summarizes the picture with respect to America's light metals, those metals that depend largely upon availability of power for their production. The sources of all three are vast and readily available in the Western Hemisphere. Production will depend largely upon the development of cheap power.

The Byproduct Metals

The next group of metals to be discussed and the fifth problem affecting the nonferrous metals embrace metals that are essentially byproducts of other operations. A mine seldom produces a single metal. With application of oil flotation to low-grade metallic ores, it might well be said that everything is extracted from the pig including the squeal. Developments in flotation, especially in the science of selective or differential flotation, where one metal is floated and another is depressed in reagents that are specifically used for the purpose, have converted extraction of more than one metallic mineral from complex ores into a routine process. Suppose that an ore contains lead, zinc, and copper; it now becomes possible to extract not only the lead

but also the zinc and copper. In some instances all three of these are extracted, plus other metals or minerals that may have considerable value as rare substances. Under certain conditions, lead may be considered a byproduct of a zinc operation and vice versa. Cadmium, which has become an important industrial metal, is a byproduct of zinc operations. Nobody ever heard of a cadmium mine. What is true of cadmium is also true of bismuth, selenium, tellurium, arsenic, some of our antimony, and other rare materials with specialized uses. Although some of these substances are not actually metals, since they have important industrial and scientific applications, they merit discussion in this review.

As already mentioned, cadmium is a metal in this group. Cadmium minerals occur too rarely to support profitable mining, hence no ore is mined or concentrated for the recovery of cadmium alone. The metal is recovered entirely in the mining, milling, and smelting of sulfide ores containing zinc and is obtained chiefly from the zinc sulfide sphalerite, on which greenockite (cadmium sulfide) occurs as a yellow stain or coating. Although some zinc concentrates have been reported to contain as much as 1 percent cadmium, the content seldom exceeds 0.5 percent. Zinc concentrates from the Tri-State region average 0.35 percent cadmium, and concentrates from mines in the Rocky Mountain region in the far West rarely carry more than 0.2 percent. The entire domestic supply of primary cadmium is recovered, concurrently with ores of other metals, as a byproduct of the flue dusts of zinc-mine roasting furnaces and lead blast furnaces, of zinc dusts collected in the early stages of distillation in zinc retorts, and of the high-cadmium precipitate obtained in purifying zinc electrolyte at electrolytic zinc plants.

In 1949 the United States produced and shipped approximately 6,000,000 pounds of cadmium metal and a little over 350,000 pounds of cadmium compounds. During the same period, America apparently consumed slightly over 7,676,000 pounds of cadmium in all forms and imported a little less than 2,000,000 pounds of cadmium in 1948. Exports of this important metal are declining.

Cadmium has a number of significant uses. It is useful plating metal for protecting against corrosion and has a high degree of resistivity to atmospheric, alkali, and salt water action. It is also an important bearing metal and is used with varying quantities of nickel, silver, or copper, depending upon the type of bearing desired. Small quantities of cadmium metal are employed in manufacturing solder and for use in other alloys. Cadmium is not cheap. It is currently quoted at approximately $2.50 a pound, and the price has been going up steadily in recent months.

Some Specialized Metals

Two other important specialized metals are selenium and tellurium, which are both recovered as byproducts, for the most part from anode muds accumulated in the electrolytic refining of domestic and imported blister copper. Selenium is used by the glass, rubber, and electronics industries for decolorizing, acceleration, and rectifier compounds, respectively. Selenium rectifiers have been extensively used in industry for many years and as voltage rectifiers for radio and television sets. They can deliver 200 to 500 volts of direct current from a 117-volt alternating current source, eliminating a heavy and bulky transformer and rectifier tube. Selenium and tellurium, when added to steel or copper, improve their machineability to a high degree without affecting electrical conductivity. Tellurium is used extensively as a core wash in foundries as a chill inducer for iron castings. Germanium, another important byproduct metal, is recovered from zinc smelters treating germaniferous ores. Germanium has many applications in the electronics industry as the key component in the diminutive crystal units used for rectifying radio-frequency currents ranging up to about 100 megacycles. Large numbers of germanium diodes are now used in the video detector circuits of television sets and in similiar electrical test equipment, Geiger counters, crystal sets, electronic computers, and telephone circuits. Other metals, of specialized usage, that are recovered from byproducts are thallium, gallium, and hafnium. Those of you who are interested in further information on these metals are referred to the latest edition of the Minerals Yearbook, published by the Bureau of Mines, which contains considerable descriptive matter on the uses of these byproduct metals.

Bismuth is another metal derived entirely as a byproduct, in this instance from the smelting of lead ores and the refining of imported bismuth bars containing lead as a major impurity. The total quantity of bismuth recovered in 1949 slightly exceeded 1948, reflecting a continued high rate of activity of primary lead smelters. Bismuth metal is consumed mainly in compounding low-fusibility alloys and pharmaceuticals used principally for treating stomach disorders. The fusible alloys of greatest utility contain 40 to 60 percent bismuth, with varying proportions of such other metals as tin, lead, cadmium, antimony, indium, and zinc. Alloys of this type have become strategic because of their time-saving applications in the aircraft, machine tool, and automotive industries. A few important uses are in bending of thin wall tubing, spotting and securing dies and punches, pattern making, and electroforming. Bismuth is also employed to a small extent in preparing phosphors, selenium rectifiers, special solders, and safety devices.

In 1949 this country imported 78 percent of its bismuth from Peru, 10 percent from Canada, 8 percent from Yugoslavia, 2 percent from Japan, and 2 percent from Korea. Exports declined sharply.

There are of course a number of other substances derived as byproducts; one of the better known is arsenic. Arsenic is seldom used as metal but as refined white arsenic is consumed principally in making calcium and lead arsenate. The calcium arsenate is employed for controlling cotton insects and the lead arsenate largely by apple growers to combat the codling moth. As an insecticide, arsenic has been replaced by some of the newer organic compounds, notably DDT. However, it still has a number of important uses in producing glass, as a wood preservative, an acide inhibitor, and for poison baits, weed killers, sheep dip, alloys, and special pharmaceuticals.

Where Price Governs New Production

During 1949 only two important mercury-producing mines were operating in the United States. Such mercury output as is available here comes largely from California, Nevada, and Oregon. Of the record receipts of metal in 1949, 94 percent was from Europe: Italy supplying 82 percent; Spain, 9 percent; and Yugoslavia, 3 percent. Most of the material that entered this country was slated for the government stockpile, and metal acquired from Italy by the Economic Cooperation Administration was bought with counterpart funds accumulated there and earmarked for such purchases.

The price of mercury has fluctuated tremendously during the last decade. The European mercury cartel (mercurio Europeo) has been able to control the market and production largely through exercising its advantage in grade of ore. Domestic producers, who on the whole, with ores of much lower grade than those from Italy and Spain, must attempt to compete with them, have again and again been forced to close operations because this country was flooded with mercury from producers in the cartel. The changing mercury prices reflected the depressed condition of the domestic industry during the past year. Late in December 1948, the Spanish-Italian cartel marked up its price for mercury $14 a flask (a flask of mercury weighs 76 pounds), reversing the downward trend that has been generally in progress since March 1945. The average price for 1949, which was $79.46 a flask, barely permitted domestic operations to exist. In 1943, during the war, the price of mercury reached a high of nearly $200 a flask, but the postwar decline in price has stopped most domestic production. Fortunately, unmined tonnages indicated by exploration work of the Bureau of Mines would be available during another period of high prices such as might prevail during a war.

Obviously, it is difficult for an industry to exist in a healthy state when it is subjected to such terrific fluctuations in product as those that attend mercury production in this country. For years the American mercury industry has been at the mercy of these economic conditions.

Mercury has a number of important uses. It is an ingredient in the manufacture of antifouling paint, it has important uses in electrical apparatus, including a new electric cell, and of course the mercury boiler is a development in which mercury has an important part. Mercury compounds are used as fungicides and bactericides in the preservation of textiles; mercury is also used in medicine and dentistry, as a catalyst, for industrial and control instruments, for amalgamation, and so on. In 1949 the United States consumed just under 40,000 flasks of mercury, but it is well to remember that in time of war, consumption would probably exceed 50,000 flasks--in 1945 it exceeded 62,000. Thus it can readily be seen that mercury is primarily a metal that is subject to the fluctuations of the market as far as domestic production is concerned, and this poses a very serious and difficult problem with respect to continuation of supply from domestic sources in times of peace. As stated previously, it is difficult if not impossible to turn production on and off as one would turn water on and off in a spigot. Unless a nucleus of production technique is retained, it is difficult to resuscitate mining operations once properties have closed down. Mercury has always been a "war baby" in this country. To a certain extent in the American metal picture it is one of the great exceptions to most metal mining in that there are virtually no byproducts. Consequently, the metal must carry costs of mining and refining, as well as depreciation.

Of course it is obvious that price is bound to govern all metal industries to some extent; but, as regards mercury, it has probably been the controlling factor with respect to domestic production. The price of copper and of land may fluctuate, but there are enough low-grade and high-grade deposits to take up the slack in the price differential.

Where Sale of a Byproduct has Provided the Necessary Stimulus

In closing, the special place that silver occupies with respect to nonferrous metals production should be noted. One of the Nation's most important lead-zinc districts is the Coeur d'Alene region in the northern Idaho panhandle. Were it not for the silver produced by these mines, in many instances it would be impossible for them to show a profit, and to a certain extent, irrespective of the wisdom of maintaining a silver price, the lead and zinc produced in the Coeur d'Alene district has been aided by the price that the producer has been able to get for his silver. This is an extremely complicated economic question--that of the price of silver--and many volumes of the Congressional Record have been filled with debates covering this subject.

The Question of Foreign Supply

The seven major questions that govern the production of nonferrous metals have been discussed. The next portion of this talk--which is of utmost concern to you as members of the armed forces--concerns

foreign supply. However, before doing this, some recapitulation is in order. This disussion has covered the seven major specific problems governing nonferrous metals production, including the problems of diminishing domestic supply with special reference to copper, lead, and zinc and of meeting future requirements for this important trio. The question of foreign availability has also been discussed, as well as the problem of power, the status of metals that are primary byproducts of other metal operations; and the problem where price governs domestic production; finally, it has been indicated how the economic output of a specific precious metal byproduct may influence the production of other less valuable metals.

The problems of foreign supply, especially during a period of actual conflict, are complex and difficult. The necessity of guarding foreign supply routes can divert military forces required for active campaigning. The United States would be in a most serious position if it did not recognize at this moment the necessity for such action. Unfortunately this country must be prepared to maintain its industrial raw material supply lines throughout the world.

It has been said that strategic minerals and metals have largely governed military strategy. Although this statement may be somewhat of an exaggeration, there is no doubt but that access to important raw materials has been an important factor in military planning throughout all recorded history. It may be recalled, for example, that Julius Caesar invaded Britain for possibly more reasons than mere conquest--he required tin to alloy with the copper from the Rio Tinto mines in Spain to furnish weapons to his legions. As late as 1914 and 1915, an important sea campaign was based upon Great Britain's deficiency in nitrates. When World War I broke out, the Germans were to all intents and purposes self-sufficient in nitrates. Professor Fritz Haber had developed a process whereby it was possible to extract nitrogen from the air. Britain did not have the Haber process and had to rely upon Chilean nitrates for its own supply. Consequently, a naval campaign early in World War I resulted in destruction of the German Pacific fleet commanded by Admiral von Spee, which was sunk off the Falkland Islands after a terrific series of sea engagements. The cost to Britain was heavy. Before the German Pacific fleet was eliminated, a British squadron commanded by Admiral Craddock was sunk, with loss of virtually all men on board, in a tragic battle near Coronel off the coast of Chile. Many of this group are familiar from personal experience with the problem of guarding American tankers in the Caribbean during World War II. Moreover, quartz, crystals, tungsten ores, and pyrethrum powder (an important ingredient for insecticides) literally had to be flown across the oceans to make up deficiencies in the supply of these important materials in the United States during the war. In World War II not only were tankers sunk at sea, but also cargo vessels containing valuable ores of bauxite, tin, copper, lead, and zinc. It was necessary

to maintain a sea route to Murmansk in order to have available supplies of Russian manganese. The problem of keeping sea lanes open to sources of strategic mineral supply is going to reappear if war breaks out. Such diversions obviously reduce the striking power of the fleet.

Coupled to the necessity for keeping the sea lanes open, every effort must be made to insure a high degree of self-sufficiency wherever possible. One of the underlying purposes of stockpiling has been to minimize diversion of forces from the major effort in case of war. Thus not only the minerals themselves are stockpiled but the time and manpower required to produce them. These are problems to be faced in the days ahead; and in the nonferrous metals field America is especially vulnerable. Upon effective judgment will rest the outcome of future conflict; without the nonferrous metals needed to furnish the necessary weapons, the strength of the Nation will decline in the very field in which it is pre-eminent--large-scale industrial production.

QUESTION: It appears that lead is now a quite important material for shielding in the development of atomic weapons and atomic energy. Does that foreshadow a greater demand for and consequent further shortage of lead?

DR. BOYD: No. We have checked into that with the Atomic Energy Commission as to the requirements for lead. Although the requirement for lead is going to be a substantial one, it is not going to result in a serious drain on our lead resources. There are other materials that can be used for shielding which are cheaper and more satisfactory than lead. When you come to the use in atomic reactors for transportation equipment, maybe some lead will be used, but there are substitutes even there that may be helpful.

QUESTION: In your talk you indicated that we are not going to get any production in some of these new metals like titanium. Do you have any prognosis on the use of titanium and whether anything is being done to develop a steady market for such metals so as to develop a source of supply in this country?

DR. BOYD: New uses for titanium are being discovered. We are expanding our industry as rapidly as it is possible to do so in the light of titanium developments. We have been working for a long time trying to find out the cheapest way to produce titanium from its ores. The only method that is really workable at this time is the Cole process. Dr. Cole is a brilliant metallurgist who came over from Luxembourg and who is helping to develop the process for us in our laboratory.

Industrially, it has not been economical to use the Cole process. It means that you have to produce magnesium first, and then you produce titanium from the magnesium compound. Then you have to regenerate the magnesium. That costs twice as much in power as would be required for aluminum.

We are expanded at the moment as much as we are likely to be if we let the industry go on its own. The price will have to go up before many years. Otherwise we won't have any titanium industry. The material industrially is selling now at about 5 dollars a pound, and I am sure that it is costing them at least 10 dollars a pound to produce it. When they get into mass production, the cost of production will come down. But we will never get the price down anywhere near that of aluminum or magnesium. I don't think it will ever come down to 50 cents. That is a crystal ball statement which no one should ever make. Someone will come along and find out how to do it. But at the moment we can see no possibility of it.

The problem here again, as in aluminum and magnesium, is to find power sources. We are talking now only on the order of 10 to 30 tons a day for the development phase. Some of that will probably go into the production of Air Force requirements.

QUESTION: You spoke about the Defense Production Authority and its connection with minerals. Would you discuss briefly the Defense Minerals Administration?

DR. BOYD: I wish I could do it as positively and as clearly as you would like to have me. The President made it very clear in his Executive order establishing the Minerals Administration to handle the Defense Production Act as it applies to minerals that it should be done as much as possible through existing agencies of the Government. That, of course, brings about complications because of having divided authority. But I am not too sure that this is going to be as bad as one might think, because cooperation is sometimes easier when you have people with responsibility in various fields who have the will to coordinate their efforts. The result was that the responsibility for the minerals field was placed in the Secretary of the Interior because there are two organizations in Interior--the Geological Survey and the Bureau of Mines--that have quite large staffs and are quite familiar with the problems. In the last war they were pretty well put aside, particularly the Bureau of Mines, and their skills not utilized to the fullest extent. The President wants the staffs of these two bureaus in the Interior Department to be utilized to the utmost. His order creates only one small coordinating staff in the Defense Minerals Administration as such.

That will be divided into three divisions. The first one is the Production Expansion Division, which will have responsibility for selecting the mines and certifying loans. The NSRB will grant certificates of necessity and guarantee the loans to the Federal Reserve banks. They will certify the loans to the RFC. The Board of Directors of RFC will not attempt to build up a staff of engineers to plan the work, as was done the last time. We will actually certify the loan to the RFC and the directors will act only as fiscal agents for it--check the financial responsibility of the parties involved, and so forth.

It will be the same way in the procurement contracts. We are working very closely with the General Services Administration now on aluminum. We will actually certify to Mr. Larsen the contracts which should be entered into for the expansion of aluminum. It is our job to develop the aluminum program and select the contractors. Having determined the contracts that we need to have, we will certify them to Mr. Larsen.

The second division is the Supply Division, which will be responsible for the programming of expansion. This division will have geologists, mining engineers, and mineralogists. They will go out in the field and develop the plans for the program and fit any projects that come in, into that program. They will have direct contact with our field staff, see where we need to invest money, either in the domestic field or the foreign. They will check into the engineering feasibility of these programs. We have one representative who will devote his time to the foreign field.

The last division, which has claimant responsibility, is the Requirements Division. They will assemble the requirements for steel, copper, and so forth for machines, motors, and so forth and take them over to the NPA and have them made available to the industries capable of producing them.

That is in general a brief summary of DMA. We will keep it quite small. I don't believe we will have more than a hundred people, including clerks, in that bureau as we have it planned. We will get most of our technical information that we need to carry on our work from the Geological Survey and the Bureau of Mines.

I speak of carrying on our work--this research work that the two bureaus will be doing is just our normal work--because we have been planning our work around these defense problems ever since the war started and even before the war. Actually it was our planning that brought about the stockpile. We have concentrated our programs on the strategic materials. A lot of our work is tied in with the stockpiling program. So we are really just carrying on work that we started before the war.

QUESTION: How does the aluminum production at the present time compare with the peak production during World War II?

DR. BOYD: My memory is not so good on some of these figures, but I would say that the production in the peak period, in 1943 and 1944--and this is total availability, from secondary and primary production in this country and imports from abroad--was 1,300,000 tons. Don't put too much faith in these figures. I will get you the right ones. Our total availability today, including about 150,000 tons a year from Canada and our domestic production and the secondary, is just a little over 1,000,000 tons.

That figure is a little less than that in the paper in your mailbox. We are sending around a correction on that, so you will have the right figure. It is just slightly below the peak. Some plants have been dismantled, but some new plants have come in. We are a little bit below our peak production at the moment. We are talking about expanding it approximately 60 percent.

Incidentally, we are trying to do this thing through private enterprise. We haven't built any new plants. We are trying to persuade private companies to expand. It is going to be most difficult to get them to do so. The progress on the aluminum expansion program has been slow.

There are four things that the aluminum-producing companies in this country tell us they want us to do if they are to expand. First, they want us to build the new plants. Second, they want us to guarantee a market for 100 percent of their product; that is, they want us to guarantee them procurement contracts. Third, they want us to guarantee them a profit. Fourth, they want us to guarantee their loans at the bank. But that would defeat our whole purpose. We want the industry to do it on its own. We would be sticking our necks out if we were to guarantee such a profit. We think industry should be willing to take some kind of risk, since it is going to own the plants. That is the kind of thing that we are working on now. It is a financial problem, which is difficult to work out.

QUESTION: I am under the impression that some tin has been discovered in Mexico. Am I wrong about that?

DR. BOYD: No. There are some small tin mines there. The quantity is not at all substantial. We are trying to find a way to get the tin out, but it will never be very significant.

QUESTION: I would like to ask a question in connection with the aluminum situation. We have had described to us an essential civilian requirement for aluminum for such things as railroad passenger and

freight cars, and so forth. Do you have any idea as to how much the utilization of aluminum has increased in essential civilian fields since the war?

DR. BOYD: That is a very difficult question to answer. I might put it this way: We have to make a pure guess at that. We don't have the information coming in that we had during the war. We don't have the consumption industry by industry. We can only make a guess. Our guess is that it will be about 200,000 tons a year. This is the figure that we are using as our top figure for essential civilian requirements.

In our modern life we are coming to consider as necessities what we used to think of as pure luxuries. Many things start out as luxuries and after a while they become necessities. I remember one schoolboy who was asked what the necessities of life are, and the first thing he put down was "an automobile." When I was going to school that was a pure luxury. Today it is a necessity. In the same way we have uses of aluminum for things that we used to consider as luxury uses, such as for the transmission of power. It will become feasible to use aluminum for that if we cannot get copper.

COLONEL GODARD: During your talk you approached the problem of shortages by saying that we should stockpile certain of these critical materials. I would like to approach that problem from another direction entirely, that is, to try to get away from these fancy steels, fancy mixtures, and so forth. What is being planned, and what are you doing in defense mobilization particularly, to make sure that we aim at minimum specifications of these scarce materials in our designs?

DR. BOYD: We haven't gotten very far into that. We have only touched the fringes in our relations with the Munitions Board. But I wouldn't be inclined to favor aiming only at the minimum--when there is enough demand for these things, someone always finds a way to get them.

Now, obviously, that is not true with some of these things. For instance, in the case of columbium, which is one of the lighter metals, with a high temperature resistance, so that it can be used in these hot spots, it would be wonderful if we could put it in jet engines and some other things. Unfortunately, if we did that in our present aircraft program, it would take more columbium annually than the total known world resources. So it is impossible to do that, and we have to design columbium out of our jet engines for the moment.

The FEA has already put in an order for a quantity of columbium to be used for defense applications. If we could use it in our jet engines, we could cut down the factor of safety in the wings tremendously, because of the reduction of rotation in the engine.

That is one problem that we ought to solve. They ought to keep that requirement before us. They ought to needle us to get after the industry for the capacity to meet their demands. They ought to keep after us, because we don't have enough production capacity now.

We should do a careful job of planning on some of these ferro-alloys, like molybdenum, tungsten, nickel, and chrome. We should plan on interchanging some of these things and using different combinations. When you come down and say, "What are the requirements for molybdenum? What are the requirements for nickel?" Somebody should be smart enough to say, "Here is a balanced requirement." Nobody has done that. That is the sort of thing that we need. We ought to be able to say, "Here is the minimum requirement for molybdenum." Then we could try to get that minimum requirement of molybdenum as fast as possible. It is going to take us some time to plan for that, but we are going to do it.

QUESTION: Can aluminum scrap be used to make aluminum?

DR. BOYD: Yes.

QUESTION: Can such aluminum be used for military purposes?

DR. BOYD: Yes. That was one of the great mistakes we made during World War II. I was told by Mr. Bunker, who was in charge of aluminum, that we did not give any credit to aluminum scrap because it was thought at that time that we could not use secondary aluminum in the manufacture of airplanes. Actually, when you use a good grade of aluminum scrap to make aluminum sheet, and use that in wing sections and other airplane parts, it is just as good as any aluminum available. They take it back and remelt and reroll it. They can use from 50 to 35 percent scrap. Of course, you can't use dirty or contaminated scrap. Actually the price of aluminum scrap is almost double, at least 50 percent higher than the price of virgin aluminum today, because there isn't much of it.

QUESTION: One of our officers tells us that uranium ore is relatively plentiful in this country, but that it is uneconomical to work the deposits because they are of low concentration, something like four parts in a million. Has any way been found to work what may prove to be a plentiful supply in this country?

DR. BOYD: I am not familiar with the whole program, because it is not all handled by us; but I will tell you what I know. I don't think there is any doubt that we all want to find new sources of concentrated ores. Obviously, there comes a time when we have to balance our manpower requirements. In terms of the dollar cost involved in getting out this uranium it is actually not expensive, but the cost in

manpower and materials is very great. If the deposits run what you say--only four parts of uranium in a million--you could literally spend the entire national energy in getting that out and producing the uranium necessary for some of these programs that they are talking about.

But we are looking for more concentrated ores all the time. The Colorado field and all that area is being very thoroughly explored for new sources of uranium. We are being constantly alerted on all new sources. But there must come a point where there must be an economic balance.

It is the same way with manganese. We have reserves of manganese in South Dakota that would run this country for many years if they could be developed. But they run only 1 percent manganese, as compared with the foreign ore average of 48 percent. When you think of the manpower it would take to dig that ore out, concentrate it, and move it to the market, it is just out of all proportion to what it would be worth.

QUESTION: Doctor, you pointed out that this country is rapidly becoming an importer of the nonferrous metals. That appears to put us in a dilemma. What does the future look like? Are you optimistic on our capability of finding substitutes? Do we have to cut down on our use of some types of these metals, especially since we are becoming dependent upon trade relations, upon various deposits that could be cut off under certain circumstances?

DR. BOYD: That is the 64-dollar question. I have been waiting for you to ask that. I don't know the complete answer. It is more than just a question of becoming dependent upon foreign sources, because there are economic factors involved.

For instance, take the availability of copper. It becomes less all the time. Some day new metallurgical processes will make the cost of extracting such that it will be possible to put other sources into production that are uneconomical now. It depends upon the working of the laws of supply and demand and the availability of deposits.

Currently, the problems are less difficult as they involve defense and security. We must try to make this country as selfsufficient as possible. Maintaining the sea lanes open in time of war means diverting some of our energy for that instead of for fighting the war. That is one of the reasons for the stockpiling program.

We haven't really found any important new mineral sources in the last 25 years. We have found one or two here and there, but they are not important. We haven't exhausted the possibilities yet. To really explore these vast unprospected areas would take the time of a lot of geologists. It would be a difficult and costly job. We haven't had to do it so far.

When we really get down to tackling it, I think we are going to find new sources. We are going to find substitutes. To say that we are a "have not" nation is begging the question. Actually when titanium really comes into the metals picture, we are going to find that we have almost inexhaustible sources of titaniferrous ores. The industry, however, must find new processes of extraction. Also we haven't really solved the metallurgical problems of magnesium. We have inexhaustible sources of that too. We have vast rock formations in this country and we can produce magnesium from sea water.

It is the same in aluminum. The only reason we have been using bauxite is because it is the cheapest source. If we could develop a process which would produce aluminum as cheaply from other sources, we would design more of it into our equipment. We have high-grade aluminum clays and some rocks contain substantial amounts of aluminum that will be used some day. The percent may not be as high as in bauxite, but the aluminum is there.

I firmly believe that the price of mineral products must rise in such a way that the producers will be able to recover in the price of the product the cost of exploration and development, the cost of finding new deposits. Somebody has to pay for that. At the present time our economic structure is not favorable toward such ventures. I think it is only fair to recognize that the cost of production is not truly reflected in the price of the minerals today. That is the kind of economic problem we are faced with, and I don't see any way of working it out until we get that done.

QUESTION: What is the possibility of substituting silver for copper in electrical circuits? Is it economical for that purpose or not?

DR. BOYD: It is not economical. Of course, during the last war they put silver bus bars in to take the place of the copper ones. And that can be done again. It was a tough job all during the war to guard those bus bars and it was expensive. Silver is still a semiprecious metal; also it has to be guarded.

QUESTION: What is the potential of Canada for copper and other nonferrous metals?

DR. BOYD: It is tremendous; Canada is a thoroughly mineralized country. Some of Canada is inaccessible and often short seasons make prospecting difficult.

I would say that outside possibly Africa, and maybe a few other areas of the world, Canada has more possibilities than any other country. It certainly has a greater mineral potential than any other country in this hemisphere. It is very difficult to prospect there, even worse than in some areas in this country, but we know the minerals are there.

QUESTION: Are there any high-grade deposits of critical materials in this country or in adjacent areas, like Canada and Mexico, that have not been worked because of engineering difficulties or because they are unexplored?

DR. BOYD: I suppose so. I don't know where they are, offhand. Mining companies and their mining engineers are always scouting for new ore deposits in Canada and Mexico. They are always working in unexplored and inaccessible areas. In fact, I don't know of many metal mines that are not remotely located. Mines are usually found in the most inaccessible places. You have to go into areas like that to find minerals. Obviously, when you discuss mineral economics, whether a mine is economic or not depends upon its accessibility and the cost of transportation.

I think that all our easily available mineral deposits in this country have been pretty thoroughly explored by the Geological Survey or the Bureau of Mines. We know of a lot of marginal mines. We know of four or five in copper. Under the current price of copper we couldn't get them developed unless we guaranteed them a market. If the price stays where it is now, 24.5 cents, any companies opening those mines would soon be out of business and would waste their money.

COMMENT: And if they were really high-grade, they would be in operation now.

QUESTION: In the ferrous metals they are beginning to prospect for them with aerial surveys, picking out things in the landscape that indicate the presence of iron ore. Is anything being done like that with the nonferrous metals?

DR. BOYD: Very definitely. We are using all these scientific methods of prospecting. When I was down in Mexico I heard that they are using the technologic approach in discovering new deposits. They made careful aerial surveys, looking for specific indications in the landscape, and had very careful analyses made by geologists. They found important new sources of rare minerals.

We have been studying all the new methods used by geologists that have been developed in the last few years. The mining operation is mainly physical--getting the ore out and bringing it into use. But a lot of these studies, such as when you start looking below the surface, when you go out and drill holes, sink shafts, and run tunnels, cost a lot of money. You must have geological knowledge at the bottom of it. You have to use not only common sense, but a lot of technical knowledge. You must have people who can use their imagination, and there has to be some chance of getting a return for their efforts. There has to be some incentive for them. If you don't have it, you are not going to solve the raw material problem.

COLONEL BERKELEY: Dr. Boyd, our animated question and answer period has indicated better than any words of mine could express our interest in your lecture. Thank you very much.

(3 Jan 1951--650)S.