CSS-jam

1 April 1939

MEMORANDUM FOR REAR ADMIRAL MC INTIRE, (MC), U.S.N.

The Problem: Find out all you can about Beryllium.

Analysis of the Problem:

History:

The oxide of beryllium was identified as a new "earth" in 1797 and dealt with extensively in the Annals of Chemistry and Physics in 1798 (1). The metal was first isolated in 1827 (2). The authoritative published work of Siemens and Halske (3) recounts the many difficulties encountered by the early investigators and the achievements of Lebeau, Fichter, and Oesterheld, As well as the eventual development of methods for commercial production. All is a comprehensive investigation of the element.

From 1833 to 1937 there were printed several important papers in the scientific literature of this country, but no important paper has been found for 1938 or 1939. The radio and popular press has hinted at developments, but convincing details are lacking. "Germany's Up in the Air" (4) is a late hint at with-held information on the new developments in the metalurgy of beryllium. The Bureau of Construction and Repair has been most helpful, but skeptical of some of the popular claims concerning epochal discourses concerning this element. The same statement holds for numerous other technical sources. However, there is an abiding conviction that there is more than popular appeal behind clever propaganda. This statement is based upon the fact that this element has not been sufficiently studied or the data sufficiently consistent to warrant calculations (5).

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(1) L.N.Vauquelin: Ann. de Chem. et de Phys. (1798) (1) 26, 155-179.
(2) F. Wohler; Ann. der Phys. & Chem. (Poggendorff) 1828, 13577-582.
(3) Siemens Konzern; Beryllium, its production and application. Chem. Catalog Co (Rheinhold Pub.Co.) 1932.
(4) Ken; April 6, 1939, p. 18.
(5) Contributions to the Data on Theoretical Metallurgy. V. Heats of Fusion of Inorganic Substances. K. K. Kelly. Bull. 393. U.S. Dept. Interior, 1938.

OCCURRENCE

Beryllium is not a particularly rare element. It is considered as being about 10 times as abundant in nature as tin, which has commonly sold for 50¢ or less per pound. Beryllium, even when alloyed, sells for $23 per pound. This is probably due to the fact that the only known (commercial) ore, beryl contains only about 4% beryllium and has been found in commercially acceptable form in some pegmatités. These in turn do not constitute more then 1% of the earth's crust and seldom include more than 1% beryl. This sparse and erratic distribution of beryl accounts for the difficulty of making estimates of the world's supply and the cost of mining, as there is little chance for other metals to bear a part of the cost of production. There is little beryllium occurring in secondary minerals so this precludes beryllium being produced as a by-product in other mining operations - that is; it is too diluted to be recovered on a commercial basis.

In view of the foregoing relating to the sparse occurrence it may seem paradoxical to report that at present more ore is offered than consumers can use. Industry would not be justified in expansion until regular and adequate supplies of the ore are assured. Doubtless the demand for beryllium alloys would be brisk and industry would rapidly expand if the price were cut from $23 to $10 or $5 per pound (1). In which case the steel industry would probably absorb great quantities. The metallurgy of beryllium is much more complex than that of tin. Processes are available whereby the metal or its alloys could be produced at only a fraction of the present small scale operation. There is need for some man to do for beryl what was done for boxite and aluminum. This probably will come, since the popular fancy has been fired by its possibilities.

It occurs in the South Dakota Black Hills, Colorado, British India and South America, Canada, Australia, Africa (1).

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(1) Paul M. Tyler - Minor Metals - Minerals Year Book 1938 - A review of 1937.

The domestic requirements of beryl for 1937 were supplied from the South Dakota Black Hills, Colorado, British India and South America. Figures on domestic production are not available, but the known imports were 173.3 short tons, valued at $7,671, of which 143.3 were from Argentina and 30 tons from British India (1).

The best known Indian deposit is at Bellore, Madras. However, beryl occurs also at Kdarma in Bihar, Padyur near Kangayan in the Coimbatore district, and in at least 2 places in Touda Hills of Rajputana. The Union of South Africa is considered one of the best reserve British sources of beryl supply. The emerald mines in the Murchinson Range near Leydsdorp in Northern Transvaal contain recoverable beryl of non gem quality. (1)

It has been reported that material carrying over 5% beryl has been mined in Little Namaqualand, Cape Province in the neighborhood of Jackals Water near Stinkopf. The reservés are said to represent hundreds of thousand tons (2). Samples of the beryl averaged 10.35% BeO. Pegmatites are found elsewhere in Africa, Canada, Australia, and South America, and probably could be found in Europe.

Consumers hope that substantially more than 10,000 tons of beryl a year could be produced from sources already investigated. The possibility always exists that a low grade deposit may be found somewhere in the world which would permit mass production methods. Laboratory findings indicate there will be no difficulty in concentrating beryl froth flotation when and if sufficiently large and uniform deposits are located and demand expands.

The domestic industry is small, but increased in 1937. An intelligent guess of the consumption of beryllium is 500 tons of beryl in the United States and probably less than 500 tons for all other countries. This includes an allowance of around 100 tons used directly in the ceramic industry. Some beryllium oxide is used in glass and ceramic glazes, as well as in superrefactories and high-duty abrasives. The production of beryllium alloys in 1937 probably did not exceed 15,000 pounds (1).

Next to the United States, Germany is the main source of beryllium products, however the little publicized Italian industry seems relatively important and experiment is under way in a number of European countries.

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(1) Minor Metals - Minerals Year Book 1938.

(2) Sanderson, L. Beryllium & its Alloys: Sands, clays and Minerals, Vol. 3, #2 Sept. 1937, pp 95-98.

Rumor has it that Japan is using 1500 Kg of beryllium annually and and expects soon to undertake production at the rate of 1,000 Kg a year (1).

The principal control of beryllium in the United States is in the Beryllium Corporation, 420 Lexington Ave., New York whose president is Andrew Gahagan. He reports that his corporation has absorbed the Brush Beryllium Co., Cleveland, Ohio, and several smaller units. The largest production laboratory is at Reading, Pa (2).

The price of beryllium-copper alloys has been reduced from $30 - $23 per pound of beryllium content. The sales doubled in 1936 and had an increase of 60% for 1937. No figures are available for 1938. These gains were probably due to selling pressure. Despite the price these alloys are still economical material for numerous special purposes, especially where high fatigue values, or wear and corrosion resistance, combined with good electrical conductivity are needed.

Beryllium-Aluminum alloys are available and are creating great interest. A master alloy of such material costs $50 per pound of contained beryllium. Alloys with nickel are available from Germany and have been promised domestically, but orders from Bureau of Construction and Repair outstanding more than a year have not been delivered (3). Exports of beryllium from the United States were prohibited in 1932 (3).

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(1) Chimie it industrie, Vol. 38, #6, Dec. 1937, p. 1311.
(2) Andrew Gahagan - Personal communication.
(3) Lt. H.V.B. Madsen (CC), USN. BuC&R. Personal communication.

Beryllium or Glucinum. Properties.

Symbol: Be. Atomic Weight: 9.1. One of the metalic chemical elements, included in the same sub-group as the periodic classification as magnesium.

It is a malleable metal of a specific gravity of 1.64 and a specific heat of 0.4079. Its melting point is below that of silver. In a fine state of division it takes fire on heating in air, but is permanent at ordinary temperatures in oxygen or air; it is readily attacked by hydrochloric and sulphuric acids, but scarely acted on by nitric acid. It behaves like aluminum when in solutions of caustic alkalies. It combines readily with flourine, bromine, chlorine, sulphur, selenium and phosphorous (1).

The metal is steel gray in color. A fractured surface exhibits a bright luster, which does not appear to change with long exposure to air, probably because of a thin, transparent protective oxide coating (2). This authority states the specific gravity is approximately 1.8.

There is no recorded actual determination of Young's modulus of elasticity, it has been estimated according to Fessenden's law to be 30,000 Kg per sq. m.m., or about 30% higher than steel (3). The electrical conductivity is approximately 1/12 that of copper.

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(1) The Encyclopaedia Britannica Vol. 3. XI Ed. p. 818.
(2) G.Melius Handbuch der Anarganischen. Ed 8.,System #26, Beryllium 48 - 71.
(3) P.Schwerber, Metallborse 1928 181 704.

The physical constants of Beryllium (1).

Atomic number	4.	Melting point	1285°C
Valence	2.	Specific gravity	1.85 at 20°C
Atomic weight	9.02	Atomic volume	4.94 to 5.30

Linear quoficient of expansion

20° - 100°	12.3×10^{-6}
200°	13.3×10^{-6}
300°	14.0×10^{-6}
500°	15.5×10^{-6}
600°	16.1×10^{-6}
700°	16.8×10^{-6}

Heat conductivity $K = 0.3847 + 0.000751t - 0.0000004688t^2 - 0.00000027t^3$

Young's modulus of elasticity	30,000 Kg per sq.m.m. (calculated)
Heat fusion	345.5 Cal. per gm.
Type of crystal lattice	hexagonal close pack
Axial ratio	1:1.58 - a = 2.283A C = 3.61A°
Hardness	120-30 Brinell (99.8 - 99.9%)
	111 Brinell (99.95)
Vapor pressure	0.001 m.m. Hg at approximately 1400°C
	5. m.m. Hg at approximately 1530°C
	760 M.m. Hg at approximately 3040°C

Electrical Conductivity, reciprocal ohms 5.41×10^4 (20°C)

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(1) L.J. Stott. Properties and Alloys of Beryllium. Am. Institute of Mining and Metallurgical Engineers Technical Publication #738.

Uses of Beryllium.

Beryllium-copper tools are widely advertised in industry as safety tools where sparking might cause an explosion or fire. These tools are represented by axes, wire brushes, hatchets, hammers, scrapers, sledges, wrecking bars, caulking tools, picks, chisels, drift pins, punches, and a wide variety of wrenches.

The heat treatment and beryllium content of the alloy permits tempering treatment to strengths comparable with good alloy steels. Thus a better tool is produced than the cheaper bronze tools for dangerous trades (1).

Further uses: Fuse clips, switch blades, vibrator arms, contact brushes, appliance plug clips, plugboard contacts, switch jaws, circuit breaker springs, relay springs, brush holder springs, electric range switch parts, thermostatic control springs, springs-leaf or helical, contact springs, spring washers, siphon bellows, diaphragms of all kinds, fountain pen clips, camera parts, instrument parts, gasoline and oil pump parts, canes, valve parts, watch parts, gears, precision bearings and bushings, plastic molds, die casting dies, welding electrodes, non sparking tools, optical alloys. Certain parts of surgical instruments (where electrical contact may be wanted). Reputed air plane construction to obtain lighter weight than aluminum and the strength of steel. This secret alloy depends not so much upon the proportion of copper beryllium, etc. as it does upon the peculiar method of mixing them (2) (3). Stott and Simonds (4) report on the advantages of Be-cu alloys for molds for plastics where fine details are required and they have a thermal conductivity more then twice that of steel - which enables shortening the moulding cycle. Such a casting can be heat treated to about 190,000 lbs. per sq. in. with a hardness of about 42.

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(1) Advertising Pamphlet - The Beryllium Corporation.
(2) Information from The Beryllium Corp., Reading, Pa.
(3) Germany's Up in the Air: Ken: April 6 - 1939 p. 19.
(4) Stott, Louis L. and Simonds, J. Earl - Modern Plastics 1937.

Rockwell C. Carson (1) reports on the quinch hardening of Be-Cu where the hardness and strength increase with high temperatures and he states that properly treated BeCu increase the service life of Pratt and Whitney controllable pitch propèààer. The high strength of beryllium-copper alloys allows the use of bearing pressures greater than 4,000 lb. per sq. in. Athough the bearing rotates only 8 degrees severe vibrations and high bearing loads caused other materials to fail in a relatively short time. With beryllium copper hubs having 380 Brinell hardness and a chrome-molybdénum steel shaft hardening to 410 Brinell, No scuffing or wear was found after more than 3,000 hours of service. Further aviation uses are indicated, but the exact use and informant are confidential. At least the BeCu alloys are characterized by unusually high wear resistance - about 5 times the wear resistance of bronze against steel.

Beryllium - Light metal Alloys.

Since Be is somewhat similar to magnesium or aluminum in properties efforts have been made to use it where lightness is required. However, the pure metal appears too brittle for structural use. More over beryllium seems to be inert with some metals or acts like silicon in the alloying effect.

Archer and Fink (2), Matignon and Calvert (3) have painted out that pure aluminum could be age hardened with beryllium. This tendency is found only to a small extent in alloys of the duralumin type 3. The resistance to wear of piston alloys can be increased.

Investigation is going on in the field of magnesium beryllium alloys (4) (5).

Lieutenant Commander Cotton in the Engineering Division of Aeronautics was frank, but skeptical concerning the utility of beryllium-aluminum alloys for structural uses (6).

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(1) Carson, Robert M: Product Engineering May 1935.
(2) Trans. Am. Inst. M.E. (1928) 78: 616.
(3) Matignon and Calvert: Compt. rend (1933) (1) 5, 1256.
(4) Louis L. Stott: Am. Instit. Mining and Metallurgical Engineers. Tech. Pub. 738, p. 3.
(5) Siemens Konzern: Wissensch. Veroff. ad. Siemens Konzern (1929-1930) 8.
(6) Personal communication.

Beryllium and Nickel

Nickel alloys can be made heat-treatable by adding small percentages of beryllium (1). Specialized equipment appears necessary for fabricating beryllium nickel alloys (2). It appears from the literature that this work has progressed much further in Germany than in this country. This alloy is exceedingly corrosion resistant and non-magnetic. These properties, combined with an elastic limit of 200,000 lbs. per square inch have caused Swiss watch makers to shift to this for main springs for high grade watches - replacing steel (3).

Orders for Bi-Ni alloys from American sources have not been filled after 1 year. There is reason to consider this for air plane protection against 30 and 50 Cal. bullets. It can be had from Germany in, rod, sheet, wire.

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(1) Masing and Kroll: U.S. Patent # 1685570.

(2) W. Hessenbrugh: Vakuumgeschmolzene Beryllium Legierungen. Heraeus Vacuumschmelze (1923-1933).

(3) Louis L. Stott. Am. Inst. Mining and Metallurgical Eng. Tech. Bul. #738, p. 11.

Ferrous Alloys

Kroll (1) - in 1936 - made a comprehensive review of the present status of Be-Fe alloys and he states that about 0.5% beryllium closes the gamma field in iron. Precipitation hardening of nickel-iron and nickel-chrome-iron alloys is possible with beryllium, but additions to the 18-8 type of stainless steel result in a ferritic alloy with considerably less corrosion resistance.

An alloy of 12 chrome, 7 nickel, 1% beryllium and no carbon can be hardened to the high value of 675 Brinell.

An austenitic beryllium-iron alloy of the type 30 chrome, 30 nickel, 1% beryllium can be cold rolled and then tempered to 500 to 550 Brinell. Invar steel with 35% nickel can be hardened to 365 Brinell when 1% beryllium is added.

In France Jospeh Laissus (2) case hardens iron and iron alloys with beryllium by cementation. He claims to obtain by this means a surface hardness on a 0.09 per cent carbon steel of 1506 Vickers, which is considerably above that which can be obtained by nitriding.

One per cent of beryllium to nickel iron alloys, with or without chromium and then precipitation - hardened results in a hard case (3). These properties are interesting and valuable for armament protection.

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(1) Dr. W. Kroll - Beryllium Iron Alloys: Metals & Alloys, Jan. 1936.
(2) J. Laissus: Compt. rend (1934) 199 1408-1409. Review de Met. (1935) 32, 293 - 301.
(3) W. Kroll: U.S. Patent 2029724.

Beryllium - precious-metal alloys.

Beryllium-Silver.

Beryllium added to silver increases the tarnish resistance (1). The disadvantage is that when in use a surface difficult to polish results, hence no development along this line goes on in the United States.

Beryllium-Gold.

The addition of 1% beryllium to fine gold results in a hardness of approximately 85 Rockwell B and a 5% beryllium gives 122 Rockwell B, or well over 400 Brinell. The disadvantage is if more than 0.5% Be is added to gold the alloy becomes too brittle to work. Thus, commercial application is to limit it to low grade gold solders and dental inlays.

Dioxidation and Desulfurization with Beryllium.

Due to the affinity of beryllium and sulphur the metal has a useful purpose as a desulfurizer (2). Beryllium will replace active reducing elements such as aluminum and calcium from their oxygen compounds and accordingly is among the best dioxidizers.Kröll (3) states "the desulphurization of steel by using Be is quite astonishing."

In Germany Be is used in amounts of 0.01 and 0.02 % to obtain dense, sound, high conductivity sand castings (4) in this country to reduce porosity of castings and sharp details on the ascast surface.

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(1) H.A. Solman: J. Institute of Metals (1934) 54-171.
(2) G. Masing: U.S. Patent 1774837.
(3) Kroll, W: Metallwirtschraft Vol. 13, Jan. 12, 1934. p. 21.
(4) E.R. Thews: Canadian Chem.& Met. (March) 1931) 78-80

What is the future of beryllium? Mr. Gahagan thinks there are tremendous possibilities if more money becomes available for research into the special uses of beryllium. Obviously research should be carried on in an intensive manner to capatalize what is already known.

SUMMARY:

The oxide of beryllium was identified in 1797, but until recent years only a few grams of the metal were produced. The cost of the metal has varied from about $5000 per pound in 1924 to $23 per pound in 1939. In mass production methods it should come down to about the price of tin - 50¢ per pound. It is certain that with a reduction in price that a great increase in use will occur.

Although of a very low specific gravity (1.84) and having a higher rigidity than steel, there appears little hope for the use of pure beryllium as a structural engineering material - at least until further research improves its value and mass production reduces the cost. It has tremendous possibilities for special uses.

Alloys of beryllium with light metals have not yet proved commercially interesting, but there is a rumor that German, Italian and possibly British sources have beat the U.S. Metallurgists to the secret of use of beryllium.

Growing uses are being found for small additions of the element to copper and nickel alloys.

Beryllium copper 72.25 Be is well established for spring use and for special purpose tools.

Germany appears to be leading the world in research on beryllium nickel alloys. Nickel with 1.8% beryllium is capable of heat treatment resulting in values as high as 260,000 per square inch tensile strength with about 8% elongation. A non-magnetic, highly corrosion-resisting beryllium-nickel-chrome-iron alloy is being used for heat resistant springs and for watch main springs.

The addition of beryllium to iron-nickel nickel-chrome-iron permits precipitation-hardening.

Claims have been made for silver-beryllium alloys to decrease the tarnish, but they are not accepted here. Gold-beryllium alloys are not sufficiently ductile for practical purposes.

The high Be-O affinity permits splendid desulfurization action ad well as deoxidation treatment. Increased study and increased demand will increase the use of beryllium and reduce the price. Beryllium exports from the United States were prohibited in 1932.

Specific information concerning the use of beryllium in the aviation industry has been difficult to obtain and even then only in a confidential manner.

Conclusions:

That: No quotation on pure beryllium was found in this country. Quotations on master alloys of beryllium with the baser metals of copper, nickel and iron range from $23 to $40 per pound of contained beryllium.

That: Wrought 22.5% beryllium is offered in standard commercial sizes and shapes.

That: Beryllium-copper safety tools are widely advertised.

That: An abiding conviction impels the conclusion that specific information concerning the use of beryllium in aviation has been withheld, both in Aeronautics and O.N.I.

That: If further information is desirec a trip to the Reading, Pa. factory, to New York to consult Mr. Gahagan and Dr. Kroll and to the Pratt and Whitney factory would be productive of the desired results.

C.S. Stephenson,
Commander (MC), U.S. Navy.
In Charge, Div. of Preventive Medicine.

CSS-jam

17 March 1939

MEMORANDUM FOR LIEUT. H.V.B. MADSEN, (CC), USN.

Herewith your notes on beryllium. This material will be kept confidential.

I am enclosing a copy for your convenience. Thank you for the trouble.

C.S. Stephenson,
Commander (MC), US.Navy.
In Charge, Div. of Prevnative Medicine.

Memorandum for File WG

17 February 1939

Subject: Use of Beryllium as an Alloying Element.

References:
(a) Memorandum for File dated 20 August 1936.
(b) Bucon letter to ONI dated 8 Jan. 1937, JJ46-(37).

1. On 15 February 1939, a conference was held in the Office of the Technical Assistant to the Chief of Naval Operations. Present at the conference were:-

Commander Graf ----------- Office of Tech. Asst.
Commander Bruner---------- Bureau of Engineering
Lieut. Madsen, (CC)------- Bureau of C&R
Mr. Andrew Gahagan ------- Beryllium Company

The purpose of the conference was to discuss with Mr. Gahagan possible uses of beryllium (glucinum) in alloys. Referennes (a) and (b) cover general discussions of this subject and are of interest in connection with this memorandum.

2. Mr. Gahagan stated that the Beryllium Company, of which he is president, has absorbed the Beryllium Corp. of America and several other smaller companies. In addition, they have affiliated with Siemens & Halske, A.G. of Germany so that the Beryllium Co. obtains all information and exclusive licenses on patents originating from Siemens & Halske. The agreement further stipulates that Siemens & Halske serves the European market and that the Beryllium Co., serves the North and South American markets. This was later changed at the request of the British Government so that England is also served by the Beryllium Company. He has also engaged Dr. Kroll of the National Physical Laboratory as consultant. The Beryllium Company has a plant at Reading, Pa. which was bought so that commercial production of Beryllium alloys could be advanced more rapidly than is now the case. While commercial production of beryllium alloys is now an accomplished fact (Anaconda), nevertheless the special processes required in melting and

CONFIDENTIAL

JJ46-(37) (S)
From: Bucon
To: ONI WG

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3. A series of articles appeared in the magazine "Metals and Alloys" starting with the July, 1936 issue which is a correlated abstract of "Beryllium and Is Alloys." Information gathered from the first of these articles indicates the present cost of beryllium is about $40.00 per pound, and that it occurs in highly complex ores widely scattered throughout the world. The largest deposits in the United States are in the Black Hills of South Dakota. Exports of this ore to foreign countries were prohibited in 1932. The article also states that, based on a steel weight of 100 duralumin would be assigned a number of 35.4 and pure beryllium 22.7.

4. From the above, it is difficult to conceive of a beryllium steel even approaching in weight that of some of the aluminum alloys, since apparently only small amounts of beryllium are used in steel. However, it is requested that the Naval Attache in Rome be instructed to gather such information as is available on this steel and also, if possible, obtain samples of the steel.

5. The Bureau has also been informed through personal correspondence that a Mr. Ernest Mayor, Clarens (Vaud), Switzerland, is working for a Swiss company which has been granted letter patents in certain European countries, and possibly the United States, for a beryllium aluminum alloy to be used as a steel addition. This alloy, the Bureau believes, is similar in general characteristics to that referred to in Mr. Hunter's letter, reference (a). It is requested that the Naval Attache at Rome also investigate the above mentioned Mr. Mayor, and obtain such information as may be possible regarding his beryllium aluminum alloy addition.

W.G. DuBOSE
ASSISTANT CHIEF OF BUREAU

JJ46-(37) (S) WG

CONFIDENTIAL JAN- 8 1937

From: Bureau of Construction and Repair.
To : Office of Naval Intelligence.

Subject: Beryllium Steel.

Reference:
(a) Letter of Herbert A. Hunter, ex ensign, USNRF dated 23 Nov. 1936.

1. This Bureau is unaware of any use in this country of beryllium steel. Last August unofficial information was received that beryllium was being used in a foreign country in the manufacture of armor plate. There is some information in the literature regarding work in England on the investigation of steels containing up to 1% beryllium for possible use in aeronautical construction. This investigation (London Engineering, September 29, 1932) indicated that little prospect of beryllium becoming a useful addition to special steels existed. Its affinity for oxygen makes its introduction into steel difficult and wasteful. A hardness peak in the tempering range of 400-450 C. exists with associated brittleness and liability to crack on cooling, due probably to a pronouncec volume change. Impact tests also indicate a tendency towards fragility.

2. Kroll (Engineering, 8 Dec. 1933), states that Be additions to nickel free steels result in brittel alloys due to coarse grained structure of the binary Be-Fe alloy. However, he adds that 5% Ni and 1% Be gives a fine grained structure. 1% of Be is equivalent to 1% of carbon as regards hardening power. Be brings about age hardening in carbon-free iron and the material can therefore be quenched and thus machined in the soft state, and then can be hardened by a comparatively low temperature ageing heat treatment. Be is better than aluminum as a deoxidázer and can completely eliminate sulphur in steel. Kroll (Beryllium, Siemes Konzern, 1932, page 280 et seq.) states that a possible use of beryllium in steels would be of the beryllium invar type (1% be, 36% ni) which is corrosion resisting and which can be rolled to thin sheets and which has a tensile strength nearly three times that of duralumin.

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and fabrication are a disadvantage and therefore production is not being pushed. Because of the great affinity of Berylloum for oxygen and nitrogen leading to poor physical properties and inability to deform plastically, melting in vacuo is most desirable. Even so, a different technique in forming is necessary and rolling speeds are low compared to those of other alloys.

3. Mr. Gahagan stated that while commercially pure beryllium could be produced for about $25 a pound, this step was hot necessary and in fact inadvisable in the case of copper alloys since it can be produced and used much more economically in the form of master alloys. Melting point of beryllium is 2336 degrees F. while non-ferrous copper base alloys have much lower melting points, thereby preventing its addition in the pure state. There has also been some use of beryllium oxide such as on television fluorescent screens and on coating inside of light bulbs in connection with General Electric Company's research on "cold light". Mr. Gahagan is now working with U.S. Army Ordnance in connection with gun barrels.

4. Mr. Gahagan was asked to discuss the alloys of beryllium which he considered could be used to advantage. He mentioned beryllium-copper and berylldum-nickle (2% Be, 98% Ni). The former is well known commercially through its production by the American Brass Company, but it has very little use for purposes under the cognizance of this Bureau. Regarding the beryllium-nickle alloy, Mr. Gahagan stated that this is an age hardening alloy possessing very excellent fatigue properties, tensile strength of 260,000 p.s.i. with 8% elongation and a Brinell hardness number of 460. Production of this alloy to these properties require the use of 1" working rolls with 9 backing, i.e. 20 high mill. He stated that this alloy was weldable. However, since this is a precipitation hardening alloy, the heat of welding will put the beryllium back into solution, thereby losing strength at the weld, and it is therefore evident that a subsequent precipitation treatment must be given.

5. Mr. Gahagan was then asked if any further developments has been made on Be-Al alloys (high strength-light weight alloys discussed in references). He stated that Siemens & Halske and National Physical Laboratory had given up the attempt and that his own company had spent $300,000 on research on this alloy without success. The Aluminum Company of America had collaborated on this project. While Be-Al materials could be made, the two elements were mutually insoluble, resulting

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in a mechanical mixture of high strength, brittleness and extremely high cost of manufacture.

6. Mr. Gahagan was then asked whether work was proceeding on age hardening alloys of the Be-Ni-Fe type (see references). He said that his company was not working on this at present, but expected to at a later date. He believed that both England and Germany were experimenting with this alloy.

7. Mr. Gahagan was then asked if he knew of any developments wherein beryllium had been used as an alloying element in protective plating. He stated that English aviation was using thin sheet laminations of beryllium-nickel for bullet protection around cockpits. He also stated that Siemens was installing a 50 ton vacuum furnace. Upon inquiry by Mr. Gahagan from one source, he was told that it was for Be-Ni and Be-Cu alloys. Another source stated that it was for Be-Ni-Fe alloys. Judging from the size of the furnace, it appears improbable that it would be used for the former. If used for the latter, it is possible that armor plate is contemplated.

8. It was suggested that Mr. Gahagan contact the present suppliers of Bullet Proof Steel and Special Treatment Steel, with a view to research work on protective plating containing beryllium. In the meantime, Mr. Gahagan will supply this Bureau with a plate of Be-Ni alloy 3' x 3' by 1/4" for purpose of testing ballistic qualities against 30 and 50 caliber attack.

Memorandum. WG

20 August 1936.

1. No information is available as regards the use of beryllium (glucinum) in armor plate, and for that matter very little conclusive information is avâilable as regards its use in steel. The American Brass Co. makes a Be-Cu alloy containing about 2% Be and .50% Ni, which is an age hardening alloy possessing very high physical properties.

2. There has been some work done in England in connection with the investigation steels containing up to 1% Be for possible use in aeronautical construction. This investigation (Engineering, Sept. 29, 1933) indicated that little prospect of Be becoming a useful addition to special steels existed. Is affinity for oxygen makes its introduction into steel difficult and wasteful. A hardness peak in the tempering range of 400-450° C. exists with associated brittleness and liability to crack on cooling, due probably to a pronounded volume change. Impact tests also indicate a tendency towards fragility.

3. Kroll (Engineering, 8 Dec. 1933), states that Be additions to nickle free steels result tin brittle alloys due to coarse grained structure of the binary Be-Fe alloy. However, he adds that 5% Ni and 1% Be gives a fine grained structure, 1% of Be is equivalent to 1% of carbon as regards hardening power. Be brings about age hardening in carbon-free iron and the material can therefore be quenched and thus machined in the soft state, and then can be hardened by a comparatively low temperature ageing heat treatment. Be is better than aluminum as a deoxidizer and can completely eliminate sulphur in steel.

4. It is apparent that knowledge of Be in very meagre and this is probably due to its great cost, which though now about $40.00 per pound, was in 1924 about $5,000 a pound. This no doubt limited research until recent years. However, Metals and Alloys, beginning in the July, 1936 issue, is publishing a corrleated abstract of "Beryllium and Is Alloys." An extensive bibliography is appended and it is probable that additional information in readily assimilable form will be produced in succeeding articles.