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TECHNICAL INFORMATION ON SOME RARE
METALS OF HIGH MELTING POINT

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METALS OF HIGH MELTING POINT

Pauline Barrett and Alan U. Seybolt
(Metallurgy Section, KAPL)

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This report is concerned with a listing of some of the pertinent properties of promising materials which do not form low melting alloys or brittle intermetallic compounds with uranium, and which would be ductile enough to be fabricated in the form of small tubing.

Enough is known about the behavior of chromium to rule it out from a metallurgical standpoint, but it is included for purposes of comparison, and like some of the other elements listed, it is comparatively unfamiliar as a base material for structural use.

This report is written from the viewpoint of the metallurgist, with primary attention to alloying behavior with uranium and the fabrication possibilities of the various metals. A table of the more pertinent engineering and physical data is first presented, followed by a more detailed account of a page or two. The various constants were selected as far as possible from what appeared to be the most reliable sources.

P. TITL

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PHYSICAL AND MECHANICAL PROPERTIES
OF MATERIALS

	Columbium	Zirconium	Titanium	Vanadium	Molybdenum	Chromium
	1	3,6	12,13	3	3	10,18
Melting Point	2415°C	~1700°C	1725°C	1735 ± 50°C	2625°C	1950 ± 32°C
	1	2,7	12,13	3	1	3
Electrical Resistivity, microhm-cm	13.1 @ 20°C	41 @ 20°C	55 @ 20°C	26 @ 20°C	5.7 @ 20°C	18.9 @ 0°C
	2	8	14		1,3	3,7
Thermal Conductivity cal/sec cm °C	0.132	0.040	0.036		0.346 @ 17°C	0.165
	1,2	3,6	12		3,7	3
Linear Coefficient, Thermal Expansion, 10 ⁻⁶ per °C	7.1 @ 0-100°C	6.3 @ rm temp.	9 @ 30-200°C		4.9 @ 20-200°C	6.2 @ 20°C
	1	3,9	3	3	1,3	3
Density, g/cm ³	8.57	6.52	4.54	6.0	10.2	7.19
		6,9,10	12			3
Phase Transformation	none	Hexagonal close-packed to body-centered cubic at ~865°C.	Hexagonal close-packed to body-centered cubic at 885 ± 2°C.	none	Body-centered cubic. Face centered cubic exists, but not stable above ~600°C.*	Hexagonal close-packed to body-centered at 26°C or above.

*Once transformed to body-centered cubic, it does not revert to face-centered on cooling.

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Physical and Mechanical Properties of Materials (cont'd)

	Columbium	Zirconium	Titanium	Vanadium	Molybdenum	Chromium
Tensile Modulus Elasticity 10 ⁶ psi	19 at 40°C	10.7	16.8		40 - 50	36
Poisson's Ratio	0.3	0.3	0.32		.302	
Yield Strength, 10 ³ psi, rm. temp.	24 (0.1% offset)	15.9 (0.2% offset)	62 (0.2% offset)		up to 57 (annealed)	
Ultimate Tensile Strength, 10 ³ psi	50 (annealed sheet)	38 (annealed)	78.7 (annealed)		~100	70
Reduction of Area	16% elongation in 2"	33%	55% (annealed)		~63%	
Hardness	75 BHN	~73 BHN	180 BHN	260 BHN (cold-worked)	147 BHN	
Closest distance approach of atoms, A	2.8527 b.c.c.	3.166 c.p.h.	2.915 c.p.h.	2.6274 b.c.c.	2.7196 b.c.c.	2.4929 b.c.c.

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ADDITIONAL INFORMATION ON MATERIALS

Columbium

Ultimate Tensile Strength at Elevated Temperatures (3,6)

<u>T. S.</u> <u>10³ psi</u>	<u>Temp.</u> <u>°C</u>
43	40
39	260
32	540
25	815

Alloying with Uranium:

The uranium-columbium system is fairly well established except for some details which are probably of no importance in the consideration of columbium as a material. There is apparently complete mutual solubility at a temperature in the vicinity of 1000°C. Columbium looks very promising, since it forms no low-melting alloy or intermetallic compounds with uranium. At 500°C, probable temperature during pile operation, the alloy zone might be expected to consist of some untransformed gamma uranium, but mostly alpha uranium, and a phase rich in columbium.

Effect of Oxygen, Nitrogen, and Hydrogen:(1)

	<u>Temp.</u> <u>°C</u>	<u>°F</u>	<u>Duration of</u> <u>Test Hours</u>	<u>Wt. of</u> <u>sample, g.</u>	<u>Gain in</u> <u>wt. - g.</u>	<u>Gain in</u> <u>Wt. - %</u>	<u>Elong.</u> <u>% in 1"</u>
O ₂	350	662	5	6.4964	.0034	.052	22.9
N ₂	300	572	5	9.2037	.0000	.000	14.2
	400	752	1	7.7193	.0030	.048	7.8
H ₂	200	424	5	7.4520	.0000	.000	16.7
	250	482	3	6.7120	.0000	.000	17.0
	300	572	5	5.9761	.0000	.000	15.6
	350	662	5	6.7474	.0017	.025	14.9
	400	752	1	7.4725	.0034	.046	14.4
	400	752	3	6.6523	.0065	.098	4.5

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Notes on Availability:

Columbium is usually found with tantalum in ores and the two stoutly resist separation. Columbium metal must be reduced from a pure salt. The estimated world production of columbium before the war was 360 metric tons per year. American imports of columbium were some 600,000 lbs. in 1940 and were very much higher during the war. Rod, wire, sheet, and powder are commercially available.

Fabrication Qualities:

Columbium may be readily fabricated into rod, wire, and sheet. It is anticipated that no trouble will be encountered in drawing small tubing.

Zirconium

Ultimate Tensile Strength at Elevated Temperatures⁽⁹⁾

T.S. 10 ³ psi air atm.	Temp. °C	T.S. 10 ³ psi		Temp. °C
		He atm.	H ₂ atm.	
38	40	24.0	15.0	500
27	260	10.0	7.0	700
15	540	6.6	0.5	800
5	815	1.5		1295

Alloying with Uranium:

The details of the uranium-zirconium constitutional diagram have not been worked out, but the general outline has been fairly well established. Mutual solid solubility of the two metals exists; approximately 45 weight per cent zirconium is soluble in uranium, and approximately 15 weight per cent uranium in zirconium.* There are no low-melting alloys, and no brittle intermetallic compounds. Hence, zirconium is a good possibility.

*Private communication
from A.R. Kaufmann, M.I.T.

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Effect of Oxygen, Nitrogen, and Hydrogen:

At temperatures under 200°C, zirconium is one of the most corrosion-resistant metals in existence. However, at temperatures as low as 600°C, zirconium is an excellent "getter" for oxygen, nitrogen, and hydrogen. Zirconium will absorb up to 40 atomic per cent oxygen, 20 atomic per cent nitrogen, and 5 atomic per cent hydrogen. Zirconium can be briefly heated to red heat.

Notes on Availability:

Zirconium is the eleventh most abundant element. The zirconium content of the earth's crust is estimated to be about 0.026%; thus, zirconium is actually present in larger quantities than many familiar elements such as nickel, copper, zinc, or lead. In 1944, the United States imported 21,459 tons of zirconium. Zirconium ores could readily be obtained at the rate of 60,000 tons or better of metal content per year. Zirconium is commercially available as rods and ingots.

Fabrication Qualities:

Zirconium can readily be rolled into sheet and swaged into rod and wire. It can also be drawn into wire, but with difficulty due to a seizing tendency. Some small tubing has been made.

Titanium

Yield strength at Elevated Temperatures - annealed, 0.2% offset ⁽¹⁴⁾

<u>Y.S.</u> <u>10³ psi</u>	<u>Temp.</u> <u>°C</u>
35	205
25	425
15	540

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Tensile Strength at Elevated Temperatures⁽¹⁴⁾

<u>T.S.</u> <u>10³ psi</u>	<u>Temp.</u> <u>°C</u>
52	205
36	425
16	540

Alloying with Uranium:

Very little is known about the alloying behavior of titanium with uranium. Since both the chemical and physical properties of titanium and zirconium are similar, it is expected that the alloying behavior of titanium would resemble that of zirconium, and would therefore be satisfactory. This, however, remains to be demonstrated.

Effect of Oxygen, Nitrogen, and Hydrogen:

Up to about 120°C, titanium has excellent corrosion resistance. At elevated temperatures, both O₂ and N₂ dissolve in titanium, and the metal is not useable above 500°C in the presence of either gas. It burns freely in nitrogen at 800°C and above. At temperatures above 375°C, titanium absorbs large quantities of hydrogen with the formation of an indefinite compound which decomposes upon heating in a vacuum to 1000°C.

Notes on Availability:

Titanium is the eighth most abundant element and the fourth most abundant structural element in the earth's crust. It is more abundant than zirconium, nickel, copper, zinc, or lead. Several hundred thousand tons of titanium ores are produced per year. In 1944, 241,100 tons were produced in the United States. Titanium can be obtained commercially as rods and ingots.

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Fabrication on Qualities:

Titanium can be readily rolled into sheet and it can be drawn into wire, but with difficulty because of a seizing tendency. There seems to be no reason why it could not be drawn into tubing.

VanadiumAlloying with Uranium:

Practically nothing is known about the uranium-vanadium constitutional diagram. However, there is some indication of solid solubility of vanadium in uranium.

Effect of Oxygen, Nitrogen, and Hydrogen:

Vanadium combines energetically with oxygen and nitrogen when heated. Finely divided vanadium at 1300° unites with 16.1% hydrogen to form stable vanadium hydride. It is not as reactive as zirconium or titanium.

Notes on Availability:

Vanadium is a more abundant constituent of the earth's crust than copper, lead, or zinc, but only in Peru and Colorado are ores mined solely for vanadium content. Vanadium is spread in minute quantities through the crust of the earth. In 1940, the world production of vanadium was 2,687 metric tons. The market is at present well supplied with vanadium, and there should be sufficient vanadium available for many years to come.

Fabrication Qualities:

Not much is known about the fabrication qualities of vanadium. However, it has been rolled into sheet. It appears that no particular difficulty would be experienced in working it to shape.

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Molybdenum

Ultimate Tensile Strength at Elevated Temperatures⁽¹⁾

<u>T.S.</u> <u>10³ psi</u>	<u>Temp.</u> <u>°C</u>
62	200
48	400
42	600
38	800
32	1000

Alloying with Uranium:

Molybdenum is one of the few metals which has a desirable alloying relationship with uranium. It forms no intermetallic compounds or low-melting alloys. There is extensive solid solubility of molybdenum in uranium; this decomposes eutectoidally near 600°C. Considering the characteristics of the uranium-molybdenum systems, molybdenum would be excellent material.

Effect of Oxygen, Nitrogen, and Hydrogen:

Molybdenum is not attacked by nitrogen or hydrogen, but it is readily oxidized by air at elevated temperatures. The metal wastes away rapidly because of the volatile oxide formed.

Notes on Availability:

Well over 99% of the world's production and known reserves of molybdenum have been and are in the form of molybdenite (MoS₂). The world output of molybdenum in 1943 was 35,162 tons. Molybdenum is commercially available as wire, sheet, and poor quality tubing.

Fabrication Qualities:

Molybdenum wire is readily fabricated into wire and sheet. It has the disadvantage that it is brittle as-cast; hence welded joints are

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brittle, but they possess fairly high strength. It is not as ductile as columbium, zirconium, titanium, or vanadium.

Chromium

Alloying with Uranium:

The uranium-chromium constitutional diagram is of the eutectic type at the uranium end with some solid solubility of chromium in uranium, but no detectable solubility of uranium in chromium. Chromium forms a eutectic with uranium at 5 per cent chromium and at 860°C. Intermetallic compounds are formed at about 12 per cent and above. From the viewpoint of alloying behavior, chromium does not appear to be desirable.

Effect of Oxygen, Nitrogen, and Hydrogen:

Oxygen: gain in wt., mg. per sq. dm. in 24 hours.

<u>mg.</u>	<u>Temp. °C</u>
47	700
97	800
220	900
630	1000

Notes on Availability:

Chromium is one of the rarer one-third of the elements which together comprise only 0.05% of the earth's surface. In 1938 the world production of crude chromite totaled 1,079,100 tons. United States' imports of chromic ore in 1943 totaled 928,576 tons. Pure chromium is commercially available as electrolytic lumps.

Fabrication Qualities:

The art of fabrication of chromium is not very far advanced; it is at about the same stage as the fabrication of vanadium. Chromium,

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however, is apparently a more brittle metal which can be hot worked to some extent.

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