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CRITICAL METALS CONSERVATION, RECYCLING AND SUBSTITUTION.(U)
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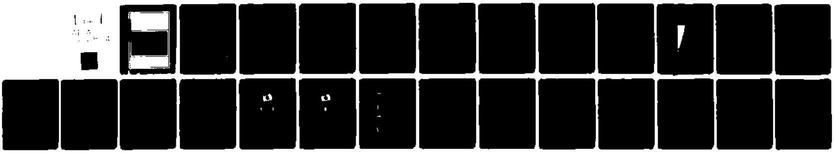

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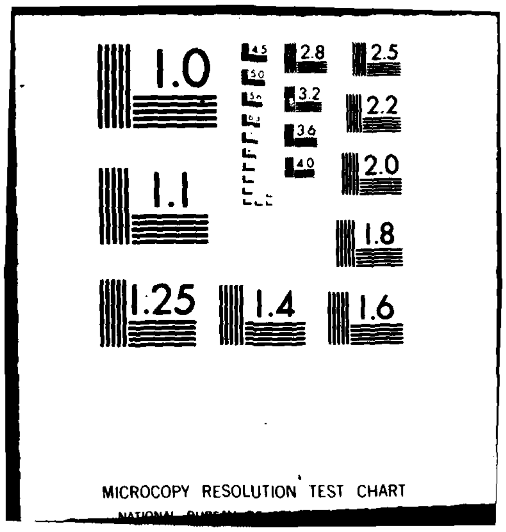

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Critical Metals Conservation, Recycling and Substitution

NORTH ATLANTIC TREATY ORGANIZATION

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NORTH ATLANTIC TREATY ORGANIZATION

ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

AGARD Report No.693

CRITICAL METALS

CONSERVATION, RECYCLING AND SUBSTITUTION

by

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USA

Paper presented at the 53rd Meeting of the AGARD Structures and Materials Panel
held in Noordwijkerhout, the Netherlands on 27 September – 2 October 1981.

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PREFACE

The drastic increase in the price of oil after the Middle East war of 1973 has emphasized the problem of availability and cost of energy for developed countries. In fact, the problem had been latent for several years and was determined by a physical factor; the total predictable amount of reserves. This had led, prior to the crisis, to the formation of an association of the producing nations which had become aware of their power. Simultaneously, and for the same reasons, concern developed for all raw materials and ores of decisive importance, with special reference to the influence of political instability in Zaire on the price of cobalt. From then on, it became clear to most countries that, in all cases, conservation, substitution and stockpiling were economical and strategic necessities. In the case of metallic elements, recycling was also considered.

The review paper by Elihu Bradley is centered on the specific problems of aircraft and aircraft engine constructuion. His extensive knowledge of the situation and the progress of technology, linked to his personal involvement with one of the world's main engine builders, has enabled him, after a review of the US aspects of the problem of availability and reliability of sources, where he draws conclusions on the sensitivity of four main elements (chromium, cobalt, tantalum and niobium) and indicates the importance to the aerospace industry of four other (nickel, tungsten, molybdenum and titanium), to describe all the technical steps which can be taken to tackle the problem.

As stressed by the author, dependence is even greater for Western European countries; this statement being alleviated by the fact that sources would then be in a friendly nation *within the NATO alliance.* Nevertheless, some differences should be stressed, linked to the importance of tungsten and molybdenum ores which are largely present in the US. It should be remembered that, in the case of molybdenum, the ratio of known reserves to the predicted demand, up to the year 2000, is only 1.5 and also, for France, that one of the main sources of nickel is under French sovereignty; this latter source including one-fourth of world cobalt resources.

Two final remarks are related, firstly, to the case of chromium. Though this element is indispensable to the aircraft engine industry, the ratio of its use in this industry to the total industrial consumption is extremely small, and the price quite moderate, compared to tantalum, for instance, which may be heavily used for turbine blade construction.

The second remark is more of a political character. For most metals, the accessible sources outside the NATO alliance are on the African continent and in Brazil. This is even clearer if we use as a reference the estimated world resources, rather than the foreign sources used presently by the US; two-thirds of tantalum, for instance, are in fact in Africa. The importance of long-term politics allowing retention of friendly relationships with the corresponding nations should be stressed.

Paul COSTA
Chairman, Sub-Committee on
Materials Recycling and Substitution

CONTENTS

CRITICAL METALS - CONSERVATION, RECYCLING AND SUBSTITUTION

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SUMMARY

In the recent past there has been increasing concern about disruptions in the price and supply of certain metals--the so-called critical elements--due to inadequate supplies to meet the demand, diminishing reserves, and political action or inaction. This paper broadly reviews the subject, identifying the critical metals relative to their current importance to the aerospace industry. The roles of conservation, recycling, substitution, stockpiling and market place operations are analyzed. New and emerging technologies are discussed relative to their effects on the critical metals, and finally some suggestions are presented for meeting future anticipated material supply problems.

The critical metals are those which have assumed an extraordinarily high significance in modern industrial technology. This paper will consider those critical metals which are of great importance to the aerospace industry; namely, cobalt, nickel, niobium, chromium, tungsten, molybdenum, tantalum and titanium. Two other elements should also be at least mentioned; manganese because it is essential to steel and vanadium as a significant alloy addition to titanium. Each of these has a number of essential uses for which economic substitutes are either unknown or inferior. In the United States, the importance of many of these metals is amplified by a high level of import dependence on a small group of nations which are generally regarded as potentially unstable (Figures 1 and 2).

There has been increasing United States concern about the critical metals. Many have spoken out on this subject. Among these are George A. Watson, Executive Director of Ferroalloys Association, in his statement on conservation, substitution and recycling to the Department of the Interior on September 28, 1978; Harry Gray, Chairman, United Technologies Corporation, talking to the American Society for Metals on the crisis in critical metals on November 14, 1979; and even more recently Senator Barry Goldwater in his Eighteenth Sight Lecture to the Wings Club on United States industry and raw materials; Admiral Willican C. Mott, now Executive Director of the Council on Economics and National Security writing on the resource war for the Smith Kline Commentary; Simon Strauss, Chairman, American Mining Congress Minerals Availability Committee in his statement before the Subcommittee on International Economic Policy of the Senate Foreign Relations Committee; and Eugene March, Group Vice President, Colt Industries Inc., speaking at the 1981 annual meeting of the American Iron and Steel Institute. In addition, a public workshop on conservation and substitution technology for critical materials was held on June 15-17, 1981. The objective of the workshop, sponsored by the U.S. Department of Commerce/National Bureau of Standards and the U.S. Department of Interior's Bureau of Mines, was to provide input for the report on materials needs that the Secretary of Commerce is required to present to Congress before October of this year, as well as to point out future direction for study and action in meeting the critical materials challenge. The report is part of the requirements specified by the National Materials Policy, Research and Development Act of 1980 (PL96-479). It would seem, at long last, that attention has been focused on this important problem. This is at least a beginning. Indeed a rational national materials policy for the United States may yet emerge.

In the long run, we worry about the supply of the critical metals due to diminishing reserves (Figure 3). However, while it is true that no mineral source is inexhaustible, there are now substantial known reserves for these metals. The problem is not so much availability as accessibility and the reliability of sources. As far as the United States is concerned, the principal short term problem is dependence on imports for many of the critical raw materials and shortages that can occur due to political action or inaction. Consider these facts. The United States is a have not nation when it comes to certain critical metals. From 1950 to the present, the U.S. raw material situation has deteriorated drastically. The U.S. has never been self sufficient and today it is vulnerable to foreign producers. For chromium and cobalt, the U.S. is close to 100% dependent on imports and the primary sources for these metals are unstable or unfriendly. Chromium which is not mined at all in the United States is very important to aerospace. In fact, without chromium we cannot today make a durable and efficient gas turbine engine. The cobalt situation is similarly alarming. The United States is 97% import dependent for this metal which is also important to aerospace. The major source of supply is Zaire, a country with a history of instability. The recent price escalation with cobalt from $6.85 to $25 or higher per pound is a case in point. Cost change for all of these critical raw materials and superalloys containing these elements in the past few years, as a matter of fact, is revealing (Figures 4,5,6,7). The greatest increases have been with cobalt, tantalum and niobium. Prices for chromium, molybdenum, nickel and titanium more or less reflect inflation.

It is widely believed that the United States is heavily dependent on the developing nations of the Third World for its supplies of critical minerals. This is certainly true when one considers the emerging nations of South Africa--Botswana, Gason, Zaire, Zambia and Zimbabwe--possessing 95% of the world's chromium, 64% of its vanadium, 53% of its manganese and 52% of its cobalt. There is no question that this area of the world is a mineral treasure house. But let us not lose sight of the fact that many imports originate from Canada, Australia, the Republic of South Africa and the Soviet Union. The tabulations already presented clearly indicates this. From the standpoint of United States foreign relations regarding minerals, the problem goes beyond the developing world. For the industrialized nations of Western Europe and Japan, dependence on Third World countries as sources of mineral imports is even greater than that of the United States.

Review of supply-demand conditions for these metals under consideration shows that the supply of nickel has been adequate for current demand. Of the eight elements listed as very critical for aerospace, nickel has been most free of availability problems. Although the U.S. has a 77% import dependency, nickel comes from friendly, stable nations. The indicated balance in nickel supply and demand suggests that supply will be adequate through 1985. However, the nickel industry has experienced past volatile cyclical behavior which resulted in abnormally high nickel consumption. Despite this possibility, the nickel industry is well positioned to take advantage of increased capacity in Canada, Indonesia and Guatemala.

Titanium ore is probably one of the more readily available of the critical metals. There are abundant titanium resources widely distributed throughout the world. For comparison it should be noted that the titanium content of the earth's crust is approximately one-tenth that of iron, but 20 times more than chromium, 30 times nickel, 60 times copper, 100 times tungsten and 600 times molybdenum. Here again, although the U.S. is 39% import dependent, titanium ore comes from friendly, stable countries. The problem has been the capacity for producing titanium sponge has been insufficient for current demand. Unlike past peaks in titanium shipments, no single cause, such as an individual airplane, is the basis for the surge. There has been heavy demand in all sections of aircraft, military, commercial and small planes. Further the growth of industrial applications for titanium is a dramatic change in the industry. However, the actions of the market place are fast correcting the supply/demand imbalance. The three sponge producing countries (not counting Russia) --U.S.A., Japan and the United Kingdom-- are increasing production capacity. By 1984 it is estimated that the total capacity for titanium sponge in these countries will be $53,850 metric tons.

Although the U.S. now imports 50% tungsten, it is believed that the United States can be self-sufficient regarding this metal. With respect to molybdenum, of course, the United States exports the metal so that a temporary supply problem stems from excessive demand. Of the critical metals, then, chromium, cobalt, niobium and tantalum, all heavily imported to the U.S. and in some instances from unstable sources, appear the most likely candidates for short and long term supply problems. The other two elements mentioned, manganese and vanadium, are probably not as vital to aerospace. However, the U.S. is 95% import dependent for manganese and 27% import dependent for vanadium, and the sources could be considered either unstable or unfriendly.

In view of these data, the need for conservation, recycling and substitution for the critical metals is obvious. Interest in conservation, recycling and substitution was greatly increased, of course, by the OPEC action of 1973, 1974 which significantly increased energy costs. But these are not new concepts. Generally speaking industry has been involved in all three for years.

Conservation

The action of a free price system, if allowed to operate, will naturally result in conservation. If prices are allowed to rise, conservation is developed in design and manufacture of products. There are many examples of this. The rising cost of fuel has resulted in significantly more fuel efficient vehicles, both automotive and aircraft. The drive to conserve raw material in the manufacture of aircraft gas turbine engines has developed the concept of near net shape processing and a reduction in the buy:fly ratio (Figures 8,9,10,11,12). Increased costs in chromium have caused conservation in extraction and processing of ore and the use of ferrochrome in steel manufacture. But in the final analysis, conservation is largely technical. Technological changes in stainless steel production have reduced the loss of chromium in the process. Chromium plating techniques have been refined to be more efficient of overall chromium usage. Two problems of degradation, corrosion and wear, cause staggering loss of metal each year. Solving the technical problems in these areas alone would vastly improve conservation. It is ironic that the element that increases corrosion resistance better than any other is chromium, and a metal noted for improving wear resistance is cobalt, two of the more critical metals. It is apparent that conservation is being practiced, but every effort should be made to increase conservation of the critical elements.

Recycling

Recycling is important in the overall conservation practice. It is now going on. The collection, segregation and careful identification of scrap allow recycling and reuse of many important metals. This scrap is sophisticated material in its identification and segregation. Relative to aerospace, discarded components of gas turbine engines are identified, segregated and important quantities of critical elements are recovered and reused. In the production of the superalloys, it is common practice to use significant amounts of revert rather than formulating the alloys entirely from virgin materials. A word of caution, however, is required regarding recycling the superalloys. It is not that simple. Most of these alloys must be vacuum melted and vacuum refined; sometimes their properties can deteriorate with continued recycling. Certain elements, such as yttrium, may slag off during vacuum recycling. Further very careful sorting of alloys is essential, since contamination from elements not normally present can cause property deterioration. An even greater danger is the possibility of contaminating with small amounts of certain tramp elements --lead, bismuth, tellurium, selenium, silver and arsenic-- which in parts per million cause significant loss in high temperature strength and ductility. Thus, the aircraft engine industry faces a two-pronged problem. It is necessary to conserve and recycle in view of limited supplies of the critical elements, but great diligence is required so that the product is not compromised.

Another area involving recycling will require extensive research and development. An enormous amount of critical metal is now lost in slag, grinding dust, sludge from electro-chemical machining, and tailings. Techniques to separate and win the metals from these sludge forms will require an extensive effort, but rising metal prices may well make it economically feasible to do so.

Substitution

Materials availability problems, either short term during supply demand imbalance or long term due to resource depletion or overconsumption, increase interest in suitable substitutions. Use of substitutes can provide industry with flexibility to deal with specific shortages. Substitution has naturally occurred as prices for materials rise. New technologies have emerged not only to replace scarce or expensive materials, but also to do the job better. An outstanding example of this is the development of titanium as a structural aircraft engine material replacing alloy and corrosion resistant steels in the compressor sections. This shift to titanium saved much chromium that was used in the steel compositions. However, nobody thought much about the chromium conservation at the time, the titanium was used because it did the job better.

In order to use substitution properly in the battle against material shortages, it will be necessary to stockpile information on substitution potentials for the critical materials. An effective defense against vulnerability to critical material emergencies is increased use of substitution.

Rarely is it possible to make direct substitution of one metal for another. Substitution encompasses the multi-disciplinary field of materials science and engineering. In all instances, a change calls for an understanding of the demands of the design and the operation of the part. It is evident that the determination of substitutability in a specific product involves two basic steps: (1) determination of material requirements, and (2) evaluation of alternate material, both of which put heavy emphasis on testing and may well be time consuming.

Substitution is currently not possible for chromium. There is no apparent alternative available to impact corrosion and oxidation resistance to alloys. Development of a suitable substitute for chromium is indeed a challenging research task. The best that might come out of such work is the possibility of using lower amounts of chromium. However, new tools including computer systems are available for studying substitution and interchangeability of alloying elements.

Similar to conservation and recycling, substitution is not new. It has been going on for a long time. During World War II when the United States faced critical element procurement problems, the NE (national emergency) steels were developed as substitutes using the synergistic effect of small alloy addition of several elements replacing a large amount of the previously used single alloying element with an overall saving. Because of the recent cobalt price crisis, significant substitution has occurred in all industrial segments, including aerospace. A major aerospace market for high temperature alloys is in turbine disks. Several nickel-base alloys containing cobalt have been traditionally used in this heavy application, including Waspaloy (13% Co), Rene' 41 (11% Co), and Astroloy (17% Co). Engine designers are gradually changing the disk alloy to an established cobalt free nickel-base alloy, Inconel 718. This single substitution at Pratt & Whitney alone will reduce cobalt usage by an estimated 600,000 lbs/year. It is worth noting relative to critical elements that Inconel 718 contains 19% chromium, 5% niobium, and 3% molybdenum. In addition to the disk substitution, several turbine airfoil parts have been changed from cobalt-base cast alloys to nickel-base cast alloys; and technical work continues to focus on cobalt consumption. A paper by Koizumi, Yamazaki and Harada recently published in the Transactions of the National Research Institute for Metals entitled "Development of Cobalt-Free Nickel-Base Superalloys" states "cobalt-free alloys are desirable because shortage of the element has been a serious problem". It should be understood, however, that substitutions are not always simple and straightforward. Because of the necessity for design changes and extensive testing of alternate material, aircraft engine substitution progress is understandably slow.

Emerging Technologies

Conservation, recycling and substitution will aid in the solution of many future material supply problems. In addition, however, the impact, both positive and negative, of emerging aircraft engine material technologies on the supply of the critical metals should be considered.

Much has been publicized about the wonders of the powder rapid solidification rate process (RSR). A news item in the April 30, 1981 Christian Science Monitor proclaims that metallurgists break through the rare-elements barrier. The story goes on to state that Pratt & Whitney developed the RSR process which makes powder by very fast freezing (10^6 degree centigrade per second) and which allows the production of stainless steels and alloys without the critical element chromium. I suggest that it is much too early for such extravagant claims. Be that as it may there is little doubt that the production emergence of RSR will indeed provide new dimensions in alloy design with enhanced alloying capability and properly directed could result in useful alloys with substantially reduced amounts of the critical elements.

The significant turbine airfoil material of this decade is likely to be in the form of unidirectionally solidified single crystal. The elimination of grain boundaries allows the alloy composition to be free of elements usually added for grain boundary morphology, carbon, boron, zirconium and hafnium. Alloying is done to provide maximum strength and oxidation/corrosion resistance. It is significant to note that the Pratt & Whitney single crystal turbine blade alloy contains 12% tantalum, the largest amount of tantalum used in any superalloy. Another emerging alloy class of interest is mechanically alloyed material made from powder utilizing oxide dispersion strengthening combined in some cases with gamma prime strengthening. Relative to critical element conservation, it should be noted that these high strength, high temperature alloys do not contain cobalt and one is iron base (Figure 13).

Work continues on development of ceramics for use in heat engines because of the high temperature strength and oxidation resistance of this material class. It is not likely, however, that the lack of toughness problem will be sufficiently overcome to allow the structural use of ceramics in manned aircraft during this decade. Replacement of superalloys with ceramics would of course involve significant conservation of the critical metals.

Alloy design of the future should consider the critical element problem. As has been pointed out it will take a large effort to effectively compile information on the precise role of the alloying elements and the exact amount of the elements required. In the future the amounts of alloying elements should be specified only as required for properties, not by tradition. Wherever possible greater use should be made of the abundant elements iron and aluminum strengthened possibly by oxide dispersion. Of the elements considered in this report, nickel and titanium are relatively abundant and their use should be considered in place of the more critical elements. From the standpoint of availability in the United States, molybdenum and tungsten are not long term problems. The elements that are likely to be sensitive to availability problems are chromium, cobalt, tantalum and niobium. This information should be well publicized and whenever possible substitution for these elements should be encouraged.

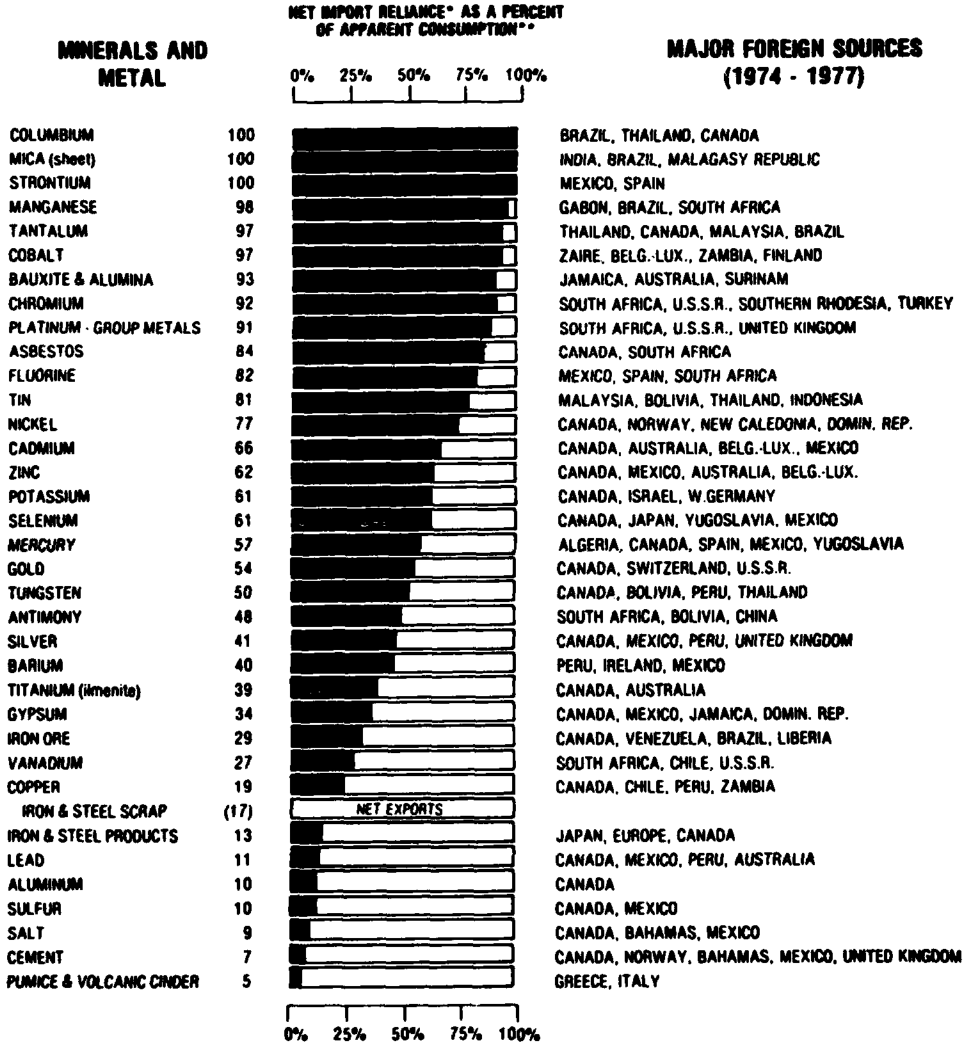
An attractive technology relative to critical metals is the field of coatings. It has long been the practice to use coatings to augment surface oxidation/corrosion resistance of many turbine engine parts operating in aggressive high temperature environment. This practice has allowed the successful use of high strength low chromium containing cast nickel superalloys. Aluminum surface conversion coatings were first used. More sophisticated overlay NiCoCrAlY type compositions deposited either by plasma or electron beam techniques are being more widely used today. Advances in surface treatment could greatly help in reducing use of the critical elements chromium and tantalum for oxidation/corrosion resistance. For example, development of ion implantation to enrich the surface metal with chromium could result in overall chromium conservation.

Conclusion

In any supply demand imbalance, it is necessary to increase the supply or to decrease the demand or both. So it is with the critical metals. The problem must be addressed on both fronts; decreased demand through diligent use of conservation, recycling and substitution, and increased supply through exploration, research and careful practice of international politics. In between reducing demand and increasing supply is the adequate stockpiling of critical metals for emergency use. The stockpile should be used to soften the impact of sudden supply dislocations. In itself it is not the answer to any long term critical metal problem. Further, the stockpile should not be used to interfere with the free price system or artificially adjust the supply and demand balances.

In the long run we must increase supplies by discovery of new mineral deposits. Therefore, we must undertake active land exploration for the critical metals with full regard for ecological considerations. The ocean floor is another rich source for minerals. We have the technology to mine the sea bed. We must get on with the international political job of determing right of access to these minerals. Finally, we must fund research in mining, refining, conservation and substitution to increase critical metal supplies. All this must be done in order to maintain an adequate future supply of these vital metals.

U.S. NET IMPORT RELIANCE OF SELECTED MINERALS AND METALS AS A PERCENT OF CONSUMPTION IN 1978



*NET IMPORT RELIANCE = IMPORTS EXPORTS + ADJUSTMENTS FOR GOV'T AND INDUSTRY STOCK CHANGES

**APPARENT CONSUMPTION = U S PRIMARY + SECONDARY PRODUCTION + NET IMPORT RELIANCE

SOURCE: U.S. Bureau of Mines

FIGURE 1

SUPERALLOY — CRITICAL ELEMENTS

% of U.S. requirements imported

	0	25	50	75	100	Source
Columbium					100	Brazil, Thailand, Nigeria, Malaysia, Canada
Manganese					98	Gabon, Brazil, S. Africa
Tantalum					97	Thailand, Canada, Australia, Brazil
Cobalt					97	Zaire, Belgium, Luxemborg, Norway, Finland
Chromium					92	S. Africa, U.S.S.R., Turkey, Rhodesia
Nickel				77		Canada, Norway, New Caledonia, Dominican Republic
Tungsten			50			Canada, Bolivia, Peru, Thailand
Titanium			39			Canada, Australia
Vanadiam		27				S. Africa, Chile, U.S.S.R
Molybdenum			(U.S. Exports)			U.S.A.

FIGURE 2

NUMBER OF YEARS TO RESOURCE DEPLETION

Critical elements in superalloys

Element	Years at 1968 usage rate	Annual growth usage %		Years to depletion	
		Average	Lowest	Average	Lowest
Nickel	150	3.4	2.8	53	58
Molybdenum	79	4.5	4.0	34	36
Titanium	111	4.1	2.8	42	51
Chromium	420	2.6	2.0	95	112
Cobalt	110	1.5	1.0	60	74
Columbium	1,000	5.25	3.5	79	102
Tantalum	335	4.42	3.75	62	70
Tungsten	40	2.5	2.1	28	29

FIGURE 3

RAW MATERIALS COST CHANGES —
Producer prices

Critical elements in superalloys

Element	1-1-78	1-1-79	Δ%	10-1-79	Δ %	21 mo.Δ%
Chromium	2.89	3.10	7.3	3.65	17.7	26.3
Nickel-columbium	16.47	18.65	13.2	35.25	89.0	114.0
Ferro-columbium	13.45	16.95	26.0	33.30	96.5	147.6
Tantalum	41.75	54.25	29.9	121.50	123.9	191.0
Cobalt	6.40	20.00	212.5	25.00	25.0	290.6
Ferro-molybdenum	4.99	6.38	27.9	6.83	7.1	36.9
Molybdenum	8.15	10.57	29.7	12.15	14.9	49.1
Nickel	2.08	1.93	– 7.2	3.00	55.4	44.2
Titanium	2.55	3.80	49.0	3.80	0	49.0

FIGURE 4

VIRGIN COST CHANGES

Material	1-1-78	1-1-79	Δ%	10-1-79	Δ%	21 mo.Δ%
Waspaloy virgin	3.02	5.10	68.9	6.60	29.4	118.5
Udimet 718 virgin	2.22	2.42	9.0	3.93	62.4	77.0

FIGURE 5

REVERT COST CHANGES

Material	1-1-78	1-1-79	Δ%	10-1-79	Δ%	21 mo.Δ%
Waspaloy revert	2.10	5.50	161.9	6.50	18.2	209.5
Udimet 718 revert	2.10	2.40	14.3	3.50	45.8	66.7

FIGURE 6

SUPERALLOY PUBLISHED PRICES*

	1-1-78	1-1-79	1-1-80	% change
Udimet 718	4.64	5.25	8.10	74
Udimet Waspaloy	5.04	9.54	12.85	154
Udimet 901	3.23	3.70	5.14	59
Udimet A-286	2.34	2.65	3.51	50

* = SMC publication, price per pound —
9″ dia. billet

FIGURE 7

GATORIZING™ PROCESS COST REDUCTION

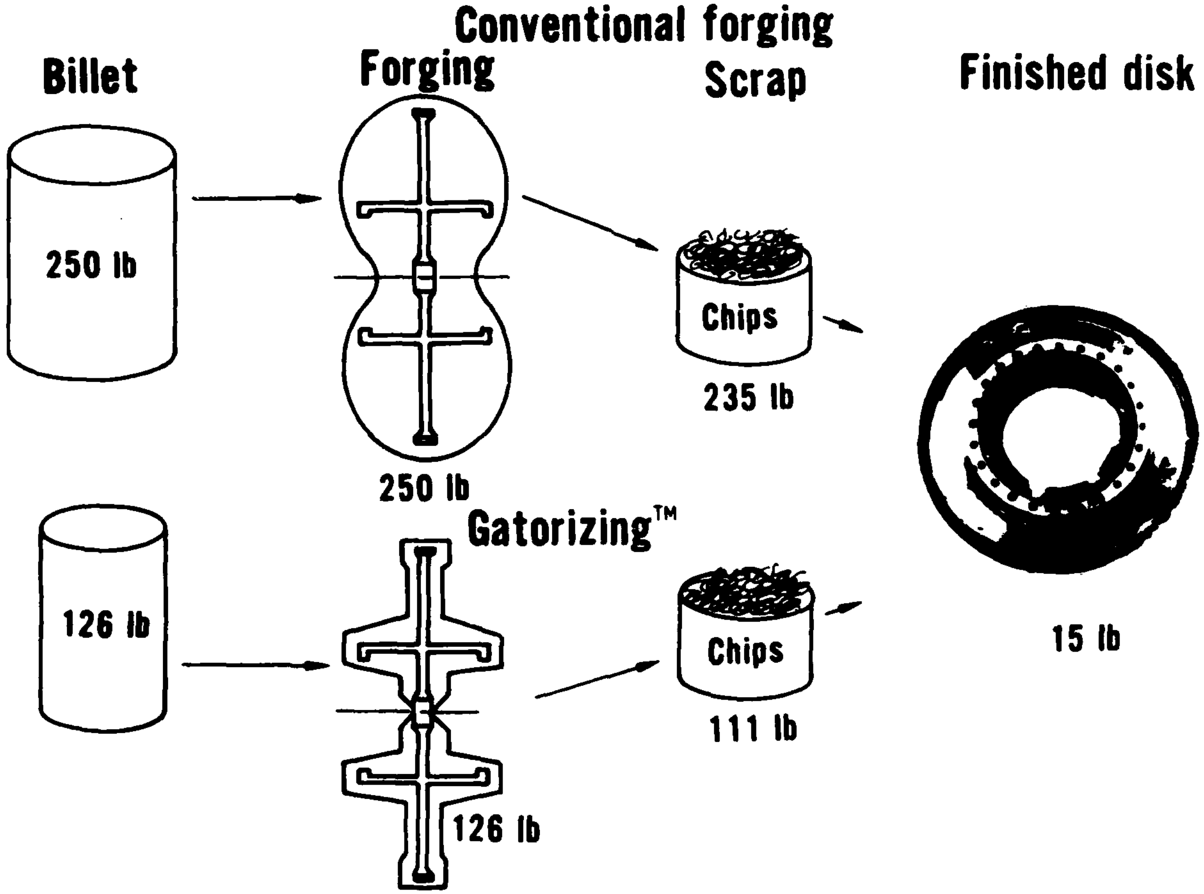


FIGURE 8

PROJECTED GATORIZING™ IMPROVEMENTS

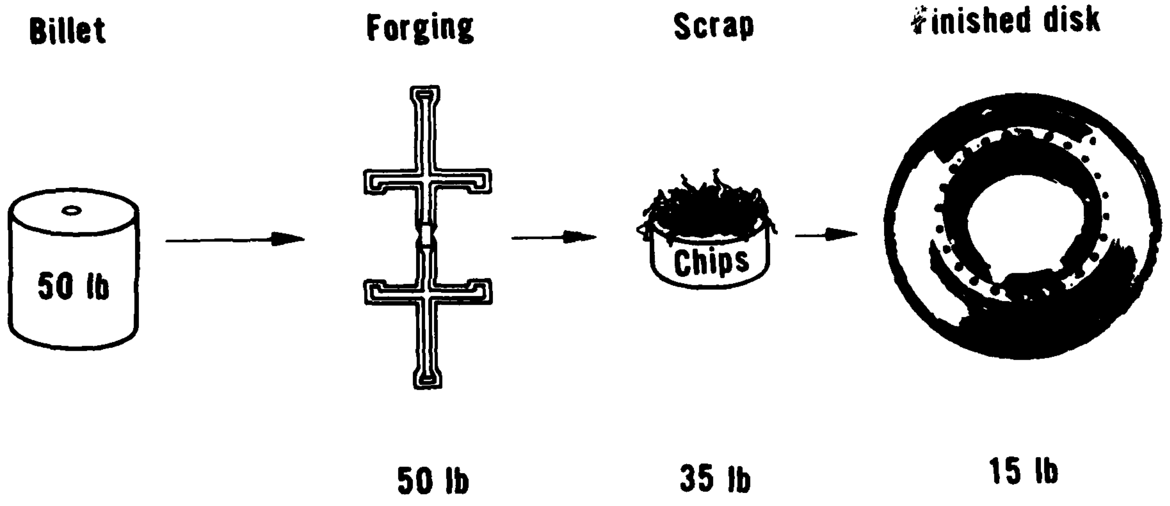
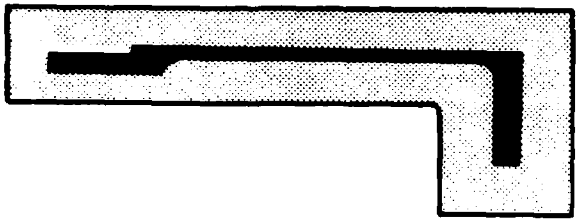
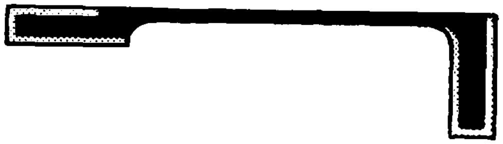


FIGURE 9

EXTRUDED AND ROLLED RING





Forged and machined ring

• Forged ring	135 lbs
• Finished ring	20 lbs
Chips	115 lbs

Extruded, rolled and welded ring

• Extruded ring	28 lbs
• Finished ring	20 lbs
Chips	8 lbs

Cost reduction 46%

FIGURE 10

MATERIAL BUY/FLY RATIO

	Buy weight (lbs)	Fly weight (lbs)	Ratio
JT3D-7	18,935	4300	4.4:1
GG4-A7	27,031	5307	5.1:1
JT12	2495	468	5.3:1
TF30-P-408	17,385	3282	5.3:1
JT8D-7	17,014	3155	5.4:1
J52-P-8A	12,042	2118	5.7:1
JT9D-3	52,242	8470	6.2:1

FIGURE 11

MATERIAL BUY/FLY RATIO

	Buy weight (lbs)	Fly weight (lbs)	Ratio
JT3D-7	18,935	4300	4.4:1
GG4-A7	27,031	[illegible]	5.1:1
JT12	2495	468	5.3:1
TF30-P-408	17,385	3282	5.3:1
JT8D-7	17,014	3155	5.4:1
J52-P-8A	12,042	2118	5.7:1
JT9D-3	52,242	8470	6.2:1
JT9D-7	47,855	8358	5.7:1

FIGURE 12

MECHANICALLY ALLOYED PRODUCTS

Alloy	Composition
MA 754	Ni — 20 Cr — 0.6 Y_2O_3
MA 956	Fe — 20 Cr — 4.5A1 — 0.5 Y_2O_3
MA 6000E	Ni — 15 Cr — 4.5A1 — 2.5 Ti — 2Ta — 4W — 2 Mo — 1.1 Y_2O_3

FIGURE 13

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14. Abstract

In the recent past there has been increasing concern about disruptions in the price and supply of certain metals – the so-called critical elements – due to inadequate supplies to meet the demand, diminishing reserves, and political action or inaction. This paper broadly reviews the subject, identifying the critical metals relative to their current importance to the aerospace industry. The roles of conservation, recycling, substitution, stockpiling and market place operations are analyzed. New and emerging technologies are discussed relative to their effects on the critical metals, and finally some suggestions are presented for meeting future anticipated material supply problems.

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