

## NIOBIUM IN PERSPECTIVE

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### Introduction

It is often customary at a major symposium such as this one to include a concluding paper which summarizes the various presentations, showing how each relates to the theme of the meeting, and which draws conclusions and makes predictions based on the data presented. However, the areas reviewed in "Niobium 81" are so diverse and in many ways unrelated that such an approach would be entirely inappropriate and a very daunting task. The only thread which connects the papers is that they all refer to some aspect of niobium - its mining, extraction and use in its various forms - and thus, I decided against summarizing the conference, but rather to touch on some of the issues which have not been discussed in other papers, thus trying to complete the niobium story as of 1981.

My primary responsibility at Niobium Products Company Limited is market development, and as I travel around the world a number of recurring questions are raised. These questions are clearly those which are of key importance in the minds of people who are using or considering the use of niobium, and I would like to answer them for the record of the symposium.

### Is niobium abundant?

Yes, niobium is present in the earth's crust at the level of 20 parts per million which, perhaps surprisingly, is more abundant than lead, tin, tungsten, tantalum and even molybdenum.

\* A wholly owned subsidiary of Companhia Brasileira de Metalurgia e Mineraçao, Araxá, M. G. Brasil.

### Is niobium available?

Yes, there are specific deposits in Brasil, Canada, Africa and China with minor deposits elsewhere (including the U.S.A.). The deposits in Brasil alone are sufficient to last, literally, for more than 500 years at twice the current useage rate.

### Is niobium a critical metal?

No. Since there are world reserves for more than 500 years, niobium cannot sensibly be described as critical.

### Is niobium a strategic metal?

No. Of the many important uses for niobium, none cannot be substituted for by other metals. Niobium is simply the best way of accomplishing many technological goals and is, almost exclusively, the most cost effective way.

For example in pipelines, molybdenum, vanadium, nickel, chromium, copper and titanium could be used in various combinations to produce X70 linepipe with acceptable toughness for almost all conceivable applications. This approach would be much more expensive than using modern niobium technology, but in strategic terms, it would be available in the case of an unlikely disruption in supply. Similar scenarios are possible in the case of high temperature alloys, stainless steels, alloy steels, etc. The only significant exception is in the area of superconductivity where niobium alloys appear to be the only currently viable alloy systems which can be used to provide superconductors for magnets. Yowever, this technology is not yet commercially or militarily significant and will remain a minor consumer of niobium in the present century.

Thus, the major niobium consuming nations of the world would be metalurgically misguided to view the metal as being "strategic".

### Is niobium versatile?

Yes. As we have learned during the symposium, niobium can do many things. It helps us to travel (aircraft turbine engines, magnetically levitated trains, trucks, automobiles, ships), it helps us to build (off-high-way bulldozers, bridges, buildings, pipelines), it helps us to drill the sea bed (offshore platforms), it helps us to produce electricity (land-based turbines) and helps us to efficiently utilize electricity (lamp fixtures), and it helps us to watch color television (lithium niobate I.F. filters). These are just a few examples of niobium's versatility.

### Is niobium expensive?

No. In comparison with the metals which could compete with niobium in its major applications, niobium is less expensive than some (V, Mo) and more expensive than others (Cr, Ni, Ti). Figure 1 shows the price change in the U.S.A. (on a per pound basis) between the late 1950's and the present time for standard grade ferroniobium. The 50's saw a rapid decline from the region of 14 dollars per pound to a low of less than 3 dollars by the early 70's. This time period saw niobium change from a scarce metal to a widely

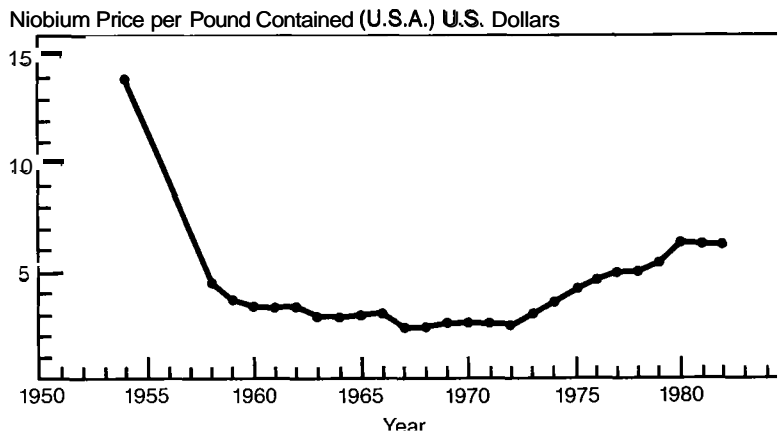


Figure 1. Price fluctuation for standard grade niobium 1954 - 1981.

available and versatile metal. The price increase since the early 1970's has followed the growth of inflation in the United States. However, if the price of niobium contained in ferroniobium is calculated in terms of swiss francs, a stable currency, it is interesting to note (1) that today's price is little changed from that of ten years ago (Figure 2).

Having disposed of these important questions, I would now like to present the rest of *my* paper in three sections - where did niobium come from (history), where is it now and where is it going.

### Historical Perspective

Niobium was discovered in 1801 by the English chemist, Charles Hatchett. He named it columbium in honor of the new world since the mineral sample he was working on came from New England. However, Hatchett did not isolate the element. This was left to Heinrich Rose, a German, who separated an impure  $Nb_2O_5$  from tantalite in 1844. Rose, thinking that he had found a new element, re-named it niobium.

The uses for niobium began around 1925 when it was added to tool steel as a substitute for tungsten and 1933 when it was first used to stabilize austenitic stainless steel. This latter use became the major application of niobium for the next thirty years. Niobium was added to superalloys for use in gas turbines in about 1935. "Niobium" was adopted as the official name by the International Union of Chemists in 1948 although the original name, columbium, is still widely used especially in the United States, Canada and Mexico.

Table I lists some basic data of relevance to niobium.

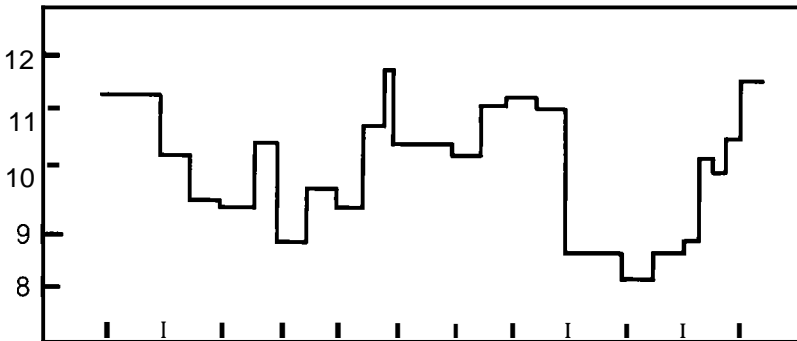


Figure 2. Ten year price fluctuation for standard grade niobium in Swiss francs.

The total known world production of niobium is shown in Figure 3 for 1980. It can clearly be seen that the consumption of niobium in North America (USA, Canada, Mexico) accounts for 41 percent of the total production, Europe 44 percent and Japan 12 percent. The use in the rest of the world accounts for the remaining 3 percent\*. The majority of high purity niobium is consumed in the United States (70 percent) while Europe only consumes about 20 percent. Japan processes about 12 percent of high purity niobium\*.

The use of niobium metal and niobium based alloys has been cyclical during the last ten years (Table III). The applications for such alloys are in the chemical, nuclear and superconductivity industries. Both the latter two industries are prone to "boom or bust" business cycles and hence the same applies to the usage picture. For many years it has been predicted that superconductivity technology is on the verge of rapid development and commercialization. A world market survey recently completed for CBMM has concluded that, on the contrary, growth will be experienced in the application of superconducting magnets and other devices, but this growth is likely to be relatively modest until the end of this century. A summary of the niobium demand analysis in superconducting devices is shown in Table IV. It can be seen from this summary that the two applications which will be significant before the end of the century are predicted to be magnets for nuclear magnetic resonance (NMR) applications especially in hospital diagnostics (body scanners) and later in nuclear fusion devices. A copy of the detailed justification for the data in Table IV is available from Niobium Products Company Limited at its Pittsburgh office.

The future for the use of ferroniobium is probably more complex. However, a simple view states that, as in the past, as the world population grows, then steel consumption will also grow to provide transportation systems, houses, factories, and offices for the increased population. The amount of HSLA steel will thus grow as the market grows, but more importantly, the proportion of HSLA steel in the product mix will also grow with the realization that substantial material savings can result from the use of these stronger steels. Figure 4 shows the trend in this respect throughout the last decade in the USA. The proportion of HSLA steel shipments (AISI

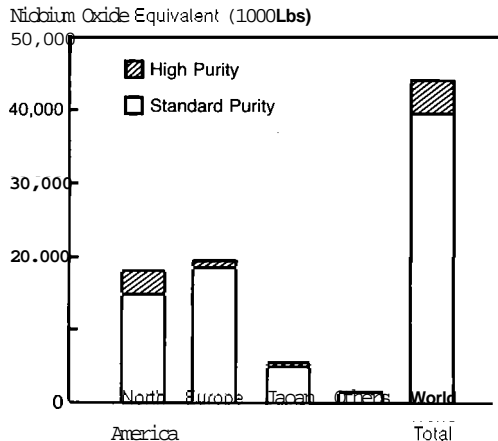


Figure 3. Niobium consumption 1980 - geographical distribution.

\* This analysis does not reflect any production of niobium in the Communist countries.

Table I. Niobium Properties

Discovery:	C. M. Hatchett, 1801, England, who named it columbium after the American origin of his ore samples.
Isolation:	H. Rose, 1844. Germany, who renamed it niobium after Niobe, daughter of the mythical King Tantalus. The designation niobium was officially adopted by the International Union of Chemists in 1951.
Atomic number:	41
Atomic weight:	92.91
Atomic volume:	10.83 cm <sup>3</sup> /g-atom
Lattice type:	BCC
Lattice constant @ 20C (68 F)	0.3294 nm (3.294 Å)
Thermal neutron cross section:	1.1 barns
Melting point:	2468 C (4474 F)
Coefficient of thermal expansion:	
500 C (932 F)	74.7 x 10 <sup>-7</sup> °C <sup>-1</sup>
700 C (1292 F)	76.32
900 C (1652 F)	77.94
1000 C (1932 F)	78.84
Thermal conductivity:	
302 C (575 F)	53.6 (31)
799 C (1470 F)	57.1 (33)
Specific heat:	0.065 cal/g°C @ 20 C
Spectral emissivity:	
@ 0.667 μ	0.374
Recrystallization temperature:	899-1204 C (1650-2200 F)
Stress relieving temperature:	760-802 C (1400-1475 F)
Heat of fusion:	68.95 cal/g
Electrical conductivity:	
@ 24 C (75 F)	12% IACS
Electrical resistivity:	17 x 10 <sup>6</sup> ohm-cm
@ 899 C (1650 F)	50 x 10 <sup>6</sup>
Thermionic work function:	4.01 eV
Electron emission:	37 A-cm <sup>2</sup> , 0K <sup>2</sup>
Magnetic susceptibility:	2.28 x 10 <sup>-6</sup> CGS
Total emissivity:	
@ 1500 C (2732 F)	0.19
@ 2000 C (3632 F)	0.24
Positive ion emission:	5.5 eV
Ionization potential:	6.77 v
Total radiation:	
1880 C (3416 F)	22 W/cm <sup>2</sup>
1980 C (3596 F)	30
Specific gravity:	8.57 g/cm <sup>3</sup>
Refractive index:	1.80
Tensile strength, typical:	
20 C (68 F)	172 MPa
799 C (1470 F)	103
1199 C (2190 F)	34
Yield strength, typical:	
20 C (68 F)	103 MPa
799 C (1470 F)	69
1199 C (2190 F)	14
Young's modulus:	
20 C (68 F)	98.5 GPa
799 C (1470 F)	82.7
1199 C (2190 F)	75.8
1788 C (3270 F)	51.7
Poisson's ratio:	0.38
Elongation in 5 cm:	
20 C (68 F)	25%
799 C (1470 F)	30
1199 C (2190 F)	45
Typical hardness:	90 DPH, 48 R <sub>b</sub> , 81 BHN, 250 Knoop

Interest in niobium containing steels can probably be traced back 40 years to the pioneering investigations of Becket and Franks (2) at Union Carbide. They showed that small amounts of niobium added to fully killed carbon steel increased the yield strength and also the tensile strength, but to a lesser extent. Becket and Franks, who confined their investigations to relatively light-gage plate, demonstrated that the use of niobium strengthening reduced reliance on conventional hardeners such as carbon, manganese, chromium and molybdenum, thereby improving weldability.

Despite the early enthusiasm for these new high-strength weldable steels, there followed a period of about 20 years during which time interest declined owing to the high cost of niobium (12-14 U.S. dollars per pound) and its lack of availability. In the 1940's and early 1950's niobium came from minor ore deposits as a by-product of tantalum operations, and was reserved for "strategic" use in high-temperature superalloys and austenitic stainless steels.

In 1954 the discovery of the Oka, Québec, pyrochlore ore body by the Molybdenum Corporation of America (Molycorp) had a significant effect on the niobium situation. This ore body was quite extensive and commercially exploitable (Table II) and a rapid decline in the price of niobium resulted (3) (Figure 1). Thus, a potentially large availability of niobium at a relatively low price spurred a number of groups to explore its use in carbon steels. For example, in 1956 the results of niobium studies at Union Carbide, United States Steel and elsewhere were included as part of a metallurgical monograph (4). The article on niobium (referred to as columbium) in this book was written by Binder who described the role of niobium in strengthening steels during heat treatment.

A strong push to develop niobium technology came from Molycorp because of their investment position in the Oka deposit. In 1957, Bill Wilson (5) of Molycorp conducted the first industrial-scale trial in cooperation with U.S. Steel (5). The trial was conducted at the Homestead (Pittsburgh) plant of U.S. Steel where 1 1/2 lbs. of contained niobium per ton of steel were added to a semi-killed carbon steel, the objective being to produce tougher ship plate (1/2" thick) by exploiting the grain refining capability of niobium. This trial was not successful because the rolling procedures were such that because of the high finish rolling temperatures used, little strain was accumulated below the recrystallization temperature and thus insufficient ferrite grain refinement resulted. However, the strengthening effect observed gave incentive for further work. In 1958, Norman Tisdale (5) of Molycorp extended this work to strip. Trials were conducted by Tisdale and Altenburger at Great Lakes Steel Corporation on their strip mill using carbon steel (C 0.2%), but with a smaller niobium addition (3/4 to 1/4 lbs. per ton). The lower finish rolling temperature and faster cooling rate inherent to thinner gage strip products gave enough grain refinement for significant improvement in toughness to be observed despite the increase in strength. The lower niobium addition also helped by reducing the strength increase. As a result of these trials in 1958, Great Lakes introduced their new niobium treated steels under the trade name GLX-W and thus this became the world's first commercially available niobium HSLA steel. Shortly after this, Gerry Barkow of the Natural Gas Pipe Company of America instigated the purchase of this material for use in an X50 pipeline project, which was the first use of a niobium containing steel in a pipeline.

Table II. Sources of Niobium  
Current Producers

<u>Location</u>	Capacity	Proven		Probable	
	Million pounds <u>Nb<sub>2</sub>O<sub>5</sub> per yr.</u>	Grade <u>%Nb<sub>2</sub>O<sub>5</sub></u>	Million lbs. <u>of Nb<sub>2</sub>O<sub>5</sub></u>	Grade <u>%Nb<sub>2</sub>O<sub>5</sub></u>	Million lbs. <u>of Nb<sub>2</sub>O<sub>5</sub></u>
Araxá, Brasil	55	3.0	4,300	3.0	23,700
St-Honore, Quebec	7.0	0.65	135	0.65	400
Catalao, Brasil	5	1.5	400	1.5	1,200
Nigeria	2	varies	limited		

Potential producers

<u>Location</u>	Proven Grade <u>%Nb<sub>2</sub>O<sub>5</sub></u>	Indicated ore reserves million pounds <u>of Nb<sub>2</sub>O<sub>5</sub></u>
Oka, Quebec	0.40	125
Tapira, Brasil	0.51	140
Moosonee, Ontario	0.65	800
Thor Lake, NWT, Canada	0.4	800
Luesha, Kivu, Zaire	29	450
Mrima Hill, Kenya	0.70	1,400

At the time of the work at Great Lakes, other steel companies were studying the use of niobium. For instance, Allen Wood Steel demonstrated similar results on their strip mill. By 1960 the use of niobium as a strengthening and toughening addition in thin-gage hot rolled steels (up to 3/8" thick) became a reality in the United States. Brochures describing these products were available from Great Lakes, Republic, Jones and Laughlin, Youngstown Sheet and Tube, Inland, Allen Wood, U. S. Steel, and others.

A major development in the niobium supply picture occurred in 1958 with the discovery of the Araxa deposit in the State of Minas Gerais in Brasil. This unique carbonatite formation was found to be extremely extensive and very rich (Table II) and was in a geographic location having the infrastructure to allow relatively rapid development. Thus, with the existence of two major developable niobium deposits, and a growing awareness of the metallurgical benefits from the use of niobium in steel, the stage was set in 1960 for the growth of the niobium industry on a world-wide basis.

Despite the early interest in the use of niobium in structural steel in the USA, no major studies were initiated at the laboratory level into the mechanism whereby niobium changes the properties of steel. The reason for this was possibly because of the dominant influence of NASA at the time in



the American Universities and the emphasis on space oriented studies to the exclusion of other areas such as microalloying. Whatever the reason, the major contribution to understanding the fundamentals of niobium effects in steels were done outside the U.S.A.

The science of niobium in steel was studied, in a major way, by three groups in the Sheffield area in England. Probably the first was that of Jack Woodhead at the University of Sheffield. During the early 1960's, Woodhead and his students (6) made many important contributions to the fundamental understanding of the mechanisms whereby niobium influences the properties of steel. Perhaps the contribution which stands out more than others was the demonstration that the application of Hall-Petch analysis to structure-property relationships could demonstrate unequivocally that, in addition to refining the ferrite grain size of steel, niobium also caused precipitation hardening (strengthening). Although it had previously been assumed that this was the case (e.g. by Wilson in his plant trials) it had never been proven.

The second HSLA oriented group which was founded in Sheffield was that of Eric Duckworth at BRSRA. This prolific group (7) functioned throughout the 1960's and emphasized the development of an understanding of structure-property relationships and the application of these relationships in designing new microalloyed steels. Probably the most significant contribution of this group was the design of steels where the carbon content was reduced to less than 0.1 percent in the PRS concept (pearlite reduced steel).

The third Sheffield area research group functioning in the early 60's period was that of Ken Irvine at the Swinden Laboratories of the United Steel Companies in Rotherham (8). This group made many major contributions to the understanding of the role of niobium in steel.

The results of the early work of these three English groups provided the scientific foundation upon which much subsequent research was based. By the end of the decade of the 60's many other research groups around the world had begun to study niobium HSLA steels, and major contributions to the understanding of the technology were subsequently made in Continental Europe, Japan and North America.

During the decade of the 1970's the technology was transferred from the laboratories into production plants and many applications for niobium-microalloyed HSLA steels were found from high-pressure gas pipelines through ship-plate, truck frames, automobiles. Probably the single most important development during this decade was the refinement of rolling schedules to permit the production of strong and tough steels with yield strengths in excess of X70 (450 MPa) with plate thickness greater than 25 mm. In this regard, the Japanese, German, Italian and French steel companies were primarily active in achieving these goals.

#### Present and Future Position

Presently, the use of niobium as a microalloy by far dominates the consumption picture. Lesser amounts are used in stainless steel and in the various high purity forms. To demonstrate the present usage pattern, it is of help to refer to the data produced by the United States Bureau of Mines for the U.S.A., since they are, apparently, the only organization in the world which attempts to keep track of consumption statistics. Their data are shown in Table III, along with the authors estimates for niobium metal. It can be seen from Table III that the U.S.A. has seen a marked increase in niobium consumption during the last ten years. The usage of all forms of

ferro-niobium has increased from 2.59 million pounds of contained Nb in 1970 to 6.302 million pounds contained Nb in 1980. Of this later total, 3.204 million pounds were consumed in carbon and HSLA steels (microalloyed) which represents 48 percent of the total compared to 26 percent in 1970. Clearly, niobium has grown as a microalloying element much more than in any other application. By the same token, the use of niobium in stainless steels is stagnating and thus as a percentage of total useage is declining. The reason for this is that traditionally niobium found its use in austenitic stainless steels to stabilize interstitials and prevent sensitization and subsequent corrosion near to weldments. With the advent of the AOD steelmaking processes and its ability to decarburize to low levels, the need for niobium in this application has declined. With the increased use of niobium in ferritic stainless steels, this trend has been arrested somewhat, but not to a great extent. However, the future will see niobium benefit from this new application.

The use of niobium in superalloys achieved an all-time high in 1980 of 1.904 million pounds or 29 percent of the total market consumption. This increased use resulted largely from the substitution of IN 718 for Waspalloy in the intermediate temperature sections of gas turbines following the "cobalt crisis". This substitution situation will continue for the immediate future, but the overall production of superalloys has been severely reduced during 1981 because of the marked recession in the aircraft building industry. This situation will not change for some time and it will probably be 1985 before the niobium useage rate in superalloys once again achieves the 1980 level. The long-term trends for niobium in superalloys predict a consumption plateau based on current technology. The current alloys which use niobium (e.g., IN 718) are intermediate temperature alloys whereas to achieve fuel efficiency engines will have to operate at higher temperatures. Thus, research in niobium containing superalloys is needed.

Table III. Consumption pattern for Niobium in the USA.  
(U. S. Bureau of Mines - 1,000 lbs.)

	1970	% of Total 1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	% of Total 1980
<b>Steel</b>													
Carbon & HSLA	705	26	821	1,874	2,180	2,291	1,796	1,882	2,350	3,011	3,178	3,204	48
Stainless Steel	522	19	588	644	712	564	379	491	588	805	827	696	10
Full Alloy Steel	829	31	789	302	361	511	372	538	584	656	505	476	7
<b>Steel Totals</b>	<b>2,057</b>	<b>76</b>	<b>2,199</b>	<b>2,821</b>	<b>3,253</b>	<b>3,367</b>	<b>2,547</b>	<b>2,911</b>	<b>3,522</b>	<b>4,472</b>	<b>4,510</b>	<b>4,376</b>	<b>65</b>
<b>Superalloys</b>	<b>472</b>	<b>17</b>	<b>591</b>	<b>665</b>	<b>685</b>	<b>1,097</b>	<b>359</b>	<b>423</b>	<b>796</b>	<b>1,146</b>	<b>1,777</b>	<b>1,904</b>	<b>29</b>
Other Alloys	36	1	37	57	67	82	35	50	65	60	32	15	—
Miscellaneous	24	1	51	131	48	78	78	50	20	16	17	7	—
<b>Primary Totals</b>	<b>2,590</b>	<b>96</b>	<b>2,879</b>	<b>3,676</b>	<b>4,056</b>	<b>4,625</b>	<b>3,019</b>	<b>3,344</b>	<b>4,403</b>	<b>5,694</b>	<b>6,336</b>	<b>6,302</b>	<b>94</b>
Niobium Metal	119	4	115	251	262	161	108	99	190	225	331	346	5
<b>Grand Total</b>	<b>2,709</b>	<b>100</b>	<b>2,994</b>	<b>3,927</b>	<b>4,318</b>	<b>4,786</b>	<b>3,127</b>	<b>3,443</b>	<b>4,593</b>	<b>5,919</b>	<b>6,667</b>	<b>6,648</b>	<b>100</b>

Table IV. Predicted World High Purity Niobium Metal Consumption, 1981-2000

	1981-1985	1986-2000
1. NMR and Lab Magnets	25	175
2. HEP	40	80
3. Computers and Instrumentation	2	18
4. Magnetic Separation	1	2
5. SMES	4	16
6. Levitated trains	-	4 subject to 1985 decision
7. Ship Propulsion	1	9
8. Current Limiters	1	4
9. Power Transmission	Negligible	70 mainly after 1944
10. Superconducting Generators	1	11
11. Fusion	20	230
12. MHD	2	65
13. Defense	5	50
14. Gyrotrons, Isotope Separators	1	3
Total	103	737

Allowing 50 percent yield from original pure niobium metal resource to NbTi in superconducting composite, these figures for Nb metal needed round off to 200 tonnes and 1500 tonnes respectively.

data compared to the total amount of steel shipped has grown from 2.4 percent in 1970 to 5 percent in 1980. This can be seen to represent an 8 to 10 percent growth per year. Similarly, Figure 4 shows that, not unexpectedly, the overall consumption of niobium in the U.S.A. has grown at about the same rate and underscores the importance of HSLA steels in the ferroniobium picture.

### Relationship Between U.S. Niobium Consumption in Steel and HSLA Steel Production

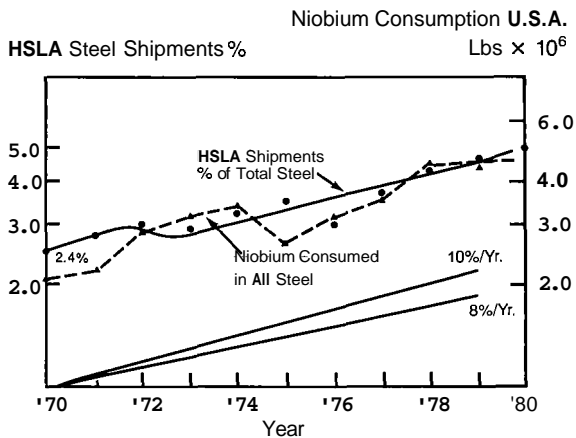


Figure 4 Relationship between U.S. niobium consumption in steel and HSLA steel production.

An alternative way to reach the same conclusion is to examine the growth in the specific niobium consumption for various countries of the world. Table V lists these data and it can be seen that most countries show increased amounts of niobium consumed per ton of steel produced over the last ten years. The main exception to this is Sweden, who because of their heavy stainless steel production, use less niobium in their AOD produced products. The world average specific niobium consumption is plotted as a function of time in Figure 5 which also shows the world niobium production for the last ten years. It can be seen that again the growth in both is between 8 and 10 percent for the last decade.

Table V. Specific Niobium Consumption-Kilo/Metric Ton Raw Steel Produced

	<u>1973</u>	<u>1974</u>	<u>1975</u>	<u>1976</u>	<u>1977</u>	<u>1978</u>	<u>1979</u>
<b>U.S.A.</b>	.0108	.0116	.0118	.0113	.0140	.0163	.0166
Canada	.0440	.0324	.0300	.0326	.0382	.0436	.0415
Japan	.0068	.0100	.0142	.0147	.0136	.0133	.0138
Austria	.0214	.0096	.0239	.0178	.0220	.0267	.0378
Belgium/Luxemburg	.0093	.0133	.0096	.0116	.0077	.0046	.0066
France	.0104	.0130	.0201	.0168	.0190	.0193	.0207
Germany	.0158	.0253	.0275	.0225	.0226	.0289	.0340
Italy	.0310	.0318	.0446	.0484	.0391	.0346	.0338
Netherlands	.0161	.0126	.0177	.0106	.0112	.0071	.0086
Spain	.0056	.0052	.0113	.0118	.0071	.0088	.0086
Sweden	.0561	.0567	.0661	.0500	.0438	.0279	.0213
<b>U.K.</b>	.0225	.0286	.0283	.0228	.0229	.0246	.0186
Australia	.0091	.0094	.0127	.0128	.0137	.0171	.0185
Brasil	.0160	.0287	.0387	.0201	.0170	.0168	.0339
<b>So. Africa</b>	.0123	.0155	.0132	.0127	.0151	.0089	.0148

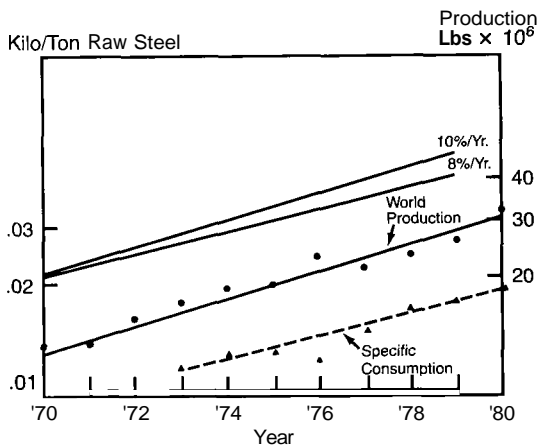


Figure 5. Relationship between world production of niobium and specific niobium consumption in steel.

## Conclusions

The decades of the 60's and 70's has seen niobium emerge from its position as a scarce exotic metal to a position of great importance especially in the worlds steel industry. The future will see niobium continue to expand in use both within its established market areas and in newer areas. The expected growth rate will be between 8 and 10 percent overall with normal short-term surges up and down according to world economic cycles.

## Reference

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