

# Rhenium

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There was no rhenium production in 1977 from domestic ore. Consumption decreased about 12% from that of 1976 to 7,300 pounds; however, it was still at a relatively high level. Imports of ammonium perrhenate reached a record high of over 6,000

pounds, or 50% more than in the previous record year of 1976. Prices for both metal powder and compounds declined to the lowest level on record. Bimetallic catalysts continued to be the major use for rhenium domestically and worldwide.

Table 1.—Salient rhenium statistics  
(Pounds of contained rhenium)

	1973	1974	1975	1976	1977
Mine production <sup>e</sup> -----	7,000	5,000	2,000	<sup>r</sup> 1,500	—
Consumption <sup>e</sup> -----	4,400	4,500	6,000	8,300	7,300
Imports (metal and scrap) -----	1,437	40	59	82	148
Imports (ammonium perrhenate) -----	<sup>e</sup> 3,040	<sup>e</sup> 3,287	<sup>e</sup> 966	4,047	6,111
Stocks, Dec. 31 <sup>e</sup> -----	20,000	24,000	21,000	<sup>r</sup> 18,300	17,300

<sup>e</sup>Estimate. <sup>r</sup>Revised.

## DOMESTIC PRODUCTION

There was no rhenium production from domestic sources in 1977; all output was on a toll conversion basis from foreign molybdenite (MoS<sub>2</sub>). This was the first year in over 20 years that no rhenium has been produced. Historically, the domestic rhenium industry has had four main producers: Shattuck Chemical Co., a subsidiary of Engelhard Minerals & Chemical Corp.;

Kennecott Copper Corp.; M & R Refractory Metals, Inc.; and Molycorp, Inc. In the past few years, only Shattuck and M & R have been actively roasting domestic and foreign MoS<sub>2</sub> concentrates for rhenium recovery. However, Cleveland Refractory Metals, a subsidiary of Kennecott Copper Corp., sold rhenium from accumulated stocks and imports to augment the domestic supply.

## CONSUMPTION AND USES

Consumption of rhenium in 1977 decreased about 12% from the record level of 1976, but it was still at a high level compared with the past several years. An estimated 80% went into platinum-rhenium bimetallic catalyst manufacture for use in petroleum-refining operations.

Semiregenerative bimetallic-reforming units in the petroleum industry increased

12% in capacity during the year, to 53.1% of total reforming capacity. This was the first time a single type of bimetallic reformer held over 50% of total reforming capacity. The total for all types of bimetallic reformers was 61.2% of total reforming capacity, the highest ever attained. This follows the trend of the past few years, brought about by the increasing demand for unleaded and

low-lead gasolines, production of which is enhanced by bimetallic catalytic reforming.<sup>2</sup>

Eight States have 100% bimetallic-reforming capacity; 22 States have none. The remaining 20 States have bimetallic capacity ranging from 30% (Ohio) to 94% (Mississippi). The trend has been to convert older monometallic units to bimetallic because increasing demand has put a strain on existing production potential.

Most of the increased capacity in catalytic reforming took place in the smaller refineries (less than 200,000 barrels per day (bpd) of crude oil capacity). Reforming capacity in these refineries increased 22% over that of 1976; similar capacity of larger refineries (greater than 200,000 bpd) was virtually unchanged in the same period. However, the total reforming capacity of the larger refineries represented 84% of total reforming capacity.

One of the advantages of platinum-rhenium catalysts is that they can tolerate more carbon than monometallic catalysts and regenerate to comparable carbon levels. One of the Union Oil Co. refineries reported 18 weight-percent carbon on a R16H platinum-rhenium catalyst, after 115 barrels of feed per pound of catalyst at about 96 research octane number (RON); 14 weight-percent on R22, a bimetallic catalyst without rhenium, after 81 barrels per pound at 92 to 96 RON; and 13 weight-percent on R16G platinum-rhenium catalyst, after 117 barrels per pound at 90 to 92 RON. Carbon deposition rates tend to be lower for bimetallic catalysts than for monometallic ones, allowing for operation at lower pressure, lower hydrogen recycle ratio, and higher severity.<sup>3</sup>

The Wynnewood refinery of Kerr-McGee Refining Corp., with a reforming capacity of 7,500 barrels per stream-day, has used a bimetallic platinum-rhenium catalyst for about 8 1/2 years. The charge has been regenerated more than seven times, approaching 800 barrels per pound on the material, and is still performing like fresh catalyst. The initial charge of bimetallic platinum-rhenium catalyst was installed in 1967 in Chevron's El Segundo No. 1 reformer. The catalyst is still in service today. Some has been replaced, but most has gone over 700 barrels per pound, and has been regenerated 15 times. Tests indicate that it is as good as fresh catalyst.

Universal Oil Products (UOP) had over 50 continuous Platforming units onstream or under construction. A 42,000 bpd unit was

placed in operation and larger ones were being designed. A valuable byproduct of the process is hydrogen, which is produced in greater amounts and at higher purity than was attainable before the continuous process was developed.

The remaining 20% of estimated domestic rhenium consumption was used in high-temperature thermocouples, X-ray tubes and targets, vacuum tube and flashbulb filaments, electrical contacts, electronic devices, heating elements, electromagnets, metallic coatings, and high-temperature alloys for research and development work.

Rhenium has experienced growth in the field of rotating anodes for diagnostic X-ray tubes. Many of the unique properties of rhenium are incorporated into composite anodes, composed of a molybdenum backing, surfaced with a tungsten-rhenium alloy layer. The rhenium content of the layer averages about 10%. Wear on the focal track is minimized because the tungsten-rhenium alloy layer withstands the electron bombardment better than pure tungsten. Also, rhenium resists the recrystallization and grain growth typical of tungsten and imparts ductility to the target surface. The composite targets have made possible the development of high-speed tubes with decreased anode angles. This permits the development of smaller focal spots without sacrificing X-ray intensity.<sup>4</sup>

A thermocouple that utilizes rhenium in two separate sections was manufactured by a domestic firm. The tube well is a Mo-50% Re alloy, and the thermocouple itself is either W versus W-26% Re or W-5% Re versus W-26% Re. Both thermocouples can be used up to 4,200° F in vacuum, or in hydrogen, nitrogen, or other inert atmospheres. The insulator used in both is beryllium oxide. Other thermocouples are available with tantalum or molybdenum tube wells and magnesium or beryllium oxide insulators in combination with both types of tungsten-rhenium thermocouples.

In modern mass spectrometry, rhenium was used in thermionic and thermoelectric emitters. The favorable combination of properties of rhenium has resulted in substantial replacement of previously used materials such as tungsten, tantalum, molybdenum, and other refractory metals. The main advantage of rhenium in this application is that it provides high stability of electronic emissions in atmospheres of various gases. This ensures higher accuracy of mass spectrometric analysis and reduces the memory effect in the instrument com-

pared with other cathode materials.

The most important advantages of rhenium as the material for ionizers in surface ionization are: Higher work function, refractoriness, and ductility over a wide temperature range. Rhenium ionizers are heat-treated to improve the work function, the best results being obtained with zone-melted rhenium.

A proprietary nickel-rhenium alloy (NR10-UP) was used to eliminate a serious problem impairing the quality of cermet tube cathodes, which had insufficient shape stability under cyclic temperature changes. The cathode core would noticeably deform after a few hundred temperature cycles. The rhenium alloy core has higher heat resistance and recrystallization temperature than the nickel-tungsten alloy (NIV06-VP) currently in use. Alloying with rhenium was more effective in retarding ther-

mal diffusion processes in nickel alloys and resulted in less softening when the tube had been heated to the working temperature. The use of the NR10-VP alloy for making the cathode core in some types of tubes increased the shape stability by 8 to 10 times, stabilized the main electrical parameters over the service life, and increased the service life from 500 to 1,000 hours.<sup>5</sup>

Rhenium continued to be used for filaments in electron tubes used in amplification, rectification, generation, direction, switching, and displaying applications. These filaments contain tungsten and molybdenum, and also rhenium in proportions up to 25 percent. Rhenium increases the ductility of the filaments and thus reduces their fragility. Rhenium applied as a coating to tungsten filaments in electron tubes increases the resistance of the filament to attack by water vapor inherent in the tube.

### PRICES

There were three reported price reductions for rhenium in 1977. At the beginning of the year, the price for rhenium metal powder was \$540 per pound, and the price for perrhenic acid ( $\text{HReO}_4$ ) was \$515 per pound. In July, the prices were reduced to \$425 and \$400 per pound for metal powder and perrhenic acid, respectively; in Sep-

tember, prices were reduced to \$395 and \$370 per pound; and in late December, prices were reduced to \$375 and \$350 per pound. Despite the decreasing trend in prices, the demand for rhenium strengthened in the last 2 years, with most of the demand coming from the petroleum industry.

### FOREIGN TRADE

Imports for consumption of ammonium perrhenate increased over 50% in 1977 to a record high level of 6,111 pounds of contained rhenium. Imports came from Chile (69%) and the Federal Republic of Germany (31%). Most of the material was directly imported; however, approximately 15% was withdrawn from bonded warehouses. Imports reached record high levels because of no domestic production, relatively high demand, and low prices.

Imports for consumption of rhenium metal powder increased to 148 pounds valued at \$55,854. Imports came from the Federal

Republic of Germany (88%) and Belgium-Luxembourg (12%).

The duty on imports of ammonium perrhenate from market economy countries was 4% ad valorem; the duty on that from central economy countries was 25% ad valorem. The duty on rhenium metal from market economy countries remained at 5% ad valorem for unwrought metal and 9% ad valorem for wrought metal. The duty on wrought and unwrought rhenium metal from central economy countries remained at 45% and 25% ad valorem, respectively.

**Table 2.—U.S. imports for consumption of rhenium metal (including scrap), by country**  
(Gross weight, pounds)

Country	1973		1974		1975		1976		1977	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Austria	—	—	—	—	1	\$300	—	—	—	—
Belgium-Luxembourg	110	\$74,500	—	—	28	11,136	17	\$8,687	18	\$4,120
Germany, Federal Republic of	1,116	782,497	40	\$27,734	30	15,760	65	29,060	130	51,734
Netherlands	211	147,679	—	—	—	—	—	—	—	—
Total	1,437	1,004,676	40	27,734	59	27,196	82	37,747	148	55,854

**Table 3.—U.S. imports for consumption of ammonium perrhenate, by country<sup>1</sup>**  
(Rhenium content)

Country	1973		1974		1975		1976 <sup>2</sup>		1977 <sup>2</sup>	
	Quantity (pounds)	Value (thousands)	Quantity (pounds)	Value (thousands)	Quantity (pounds)	Value (thousands)	Quantity (pounds)	Value (thousands)	Quantity (pounds)	Value (thousands)
Chile	—	—	1,232	\$449	—	—	1,280	\$606	4,187	\$1,087
Germany, Federal Republic of	1,450	\$1,913	1,520	1,185	401	\$165	2,767	801	1,924	533
Sweden	1,590	1,916	535	171	565	277	—	—	—	—
Total	3,040	3,829	3,287	1,805	966	442	4,047	1,407	6,111	1,620

<sup>1</sup>Years 1973 through 1975 are estimated.

<sup>2</sup>Adjusted by Bureau of Mines.

## WORLD REVIEW

Porphyry copper deposits in Canada, Chile, Peru, and the U.S.S.R. were the major worldwide sources of rhenium. Known recovery facilities outside of the United States were located in Belgium-Luxembourg, Bulgaria, Chile, France, the German Democratic Republic, the Federal Republic of Germany, Sweden, the United Kingdom, and the U.S.S.R.

**Canada.**—The Island Copper mine of Utah International, Inc., produced all of the Canadian rhenium output. In 1977, an estimated 2,000 tons of molybdenite concentrate containing approximately 5,700 pounds of rhenium was shipped to the United States. The contained rhenium was processed into ammonium perrhenate and perrhenic acid in the United States and returned to Utah International for disposition. The Island Copper ore deposit contains one of the highest concentrations of rhenium in the world, with the rhenium content consistently averaging above 1,100 parts per million in molybdenite concentrate.

Catalytic reforming capacity in Canada increased 8% during the year, resulting from pressure to produce higher octane, low-lead, and lead-free gasolines. Nearly all

of the increased capacity was accounted for by bimetallic catalysts.

**Chile.**—Rhenium production in Chile totaled an estimated 3,200 pounds contained in about 5,200 pounds of ammonium perrhenate. Potential rhenium output is steadily increasing because of increasing molybdenum capacity. This was made possible by the high molybdenum content of the porphyry copper ores and the construction of new byproduct recovery plants at Chuquicamata and Andina. As a result, rhenium production may reach 7,000 pounds per year in the near future.<sup>6</sup>

The Chilean copper mining company Compania Minera Disputada de las Condes S.A. was purchased by Exxon Corp. late in 1977. Exxon planned to carry out studies to determine the feasibility of expanding operations. Reserves of rhenium were estimated to be over 16,000 pounds averaging 350 parts per million of rhenium in molybdenite. To date, the molybdenum and rhenium have not been exploited.

Corporación del Cobre de Chile (CODELCO), the National Copper Corporation of Chile, renewed its agreement with Philipp Brothers, a division of Engelhard Minerals & Chemical Corp., to market its molybde-

num and rhenium output worldwide. CODELCO is the world's largest holder of copper reserves, and was also the world's largest byproduct molybdenum producer. CODELCO's rhenium output made Chile one of the largest rhenium producers in the world in 1977.

**Germany, Federal Republic of.**—Herman C. Starck, one of the largest processors of molybdenum and rhenium in Europe, began marketing rhenium in the United States in 1977. The main rhenium product marketed was ammonium perrhenate, but perrhenic acid and rhenium metal powder were also sold. Germany has the most rigid restrictions on the use of tetraethyl lead in gasoline in the world. To meet motor gasoline specifications that became effective January 1, 1976, \$400 million has been spent. As a result, the use of platinum-rhenium catalysts in petroleum-reforming operations increased significantly. Esso A. G., Germany's second largest refiner, switched to bimetallic platinum-rhenium catalysts in four of its reformers and substantial-

ly modified the reformers' downstream equipment. Deutsche B. P. switched from conventional to bimetallic catalysts in its Dinslaken, Hamburg, and Vohburg refineries. Wintershall A.G. was modernizing its Lingen refinery. Part of the project includes a 650,000-ton-per-year catalytic reformer and hydrogen plant. Oberrheinische Mineraloelwerk GmbH was upgrading and modernizing its Karlsruhe refinery in order to supply 15% of Germany's current gasoline demand by the end of 1978. A new continuous catalytic reformer will be installed and an existing one will be converted to desulfurization service.<sup>7</sup>

**Iran.**—A new reforming unit was being constructed as part of a petroleum-refining complex in Bandar Shahpur for the production of 500,000 tons per year of xylenes. The unit will employ Engelhard's bimetallic platinum-rhenium "Magnaforming" catalyst. This catalyst has proven itself in the United States over the past several years and is in worldwide use.

## TECHNOLOGY

Bureau of Mines researchers presented a paper<sup>8</sup> on the operation of a prototype industrial-size bipolar electrooxidation cell for the recovering molybdenum and rhenium from offgrade molybdenite concentrate. The cell was operated in cooperation with the Nevada Division of Kennecott Copper Corp. Extractions of 94% to 98% of molybdenum and rhenium were reportedly achieved from a concentrate containing up to 6% copper. The Bureau provided data on the process to aid in the technology transfer to interested industry representatives.

A process was developed for treating molybdenite concentrate containing rhenium for efficient production of high-purity rhenium and molybdenum products.<sup>9</sup> The process consists of flash roasting molybdenite concentrate in an oxygen atmosphere, wet scrubbing the roaster offgas to remove dust and volatilized molybdenum and rhenium, recovering molybdenum and rhenium by solvent extraction, precipitation, and crystallization of rhenium as a high-purity ammonium perrhenate. Rhenium recoveries of 90% from concentrates containing 1,400

parts per million of rhenium have been demonstrated in a pilot plant. Over 75% rhenium recovery has been proven from concentrates containing 250 parts per million of rhenium. Pyridene was used to extract the rhenium from the stripping solution. The pyridene extract was fed to a still where the rhenium was concentrated in the still bottoms as a sodium perrhenate solution containing up to 150 grams per liter of rhenium. The rhenium was recovered as ammonium perrhenate crystals by addition of ammonium sulfate to the still bottoms. The ammonium perrhenate was further purified by recrystallization and the pure product dried for sale or conversion to other end products.

Wide use of molybdenum-rhenium alloys with high rhenium contents for large structures is precluded due to the high cost and limited availability of rhenium. However, it has been shown that the plasticity of weld joints of low-alloy materials such as the VM1 and TsM2 alloys can be improved by alloying only the joint metal with rhenium. Increasing the rhenium content in

the joint beyond 50% results in a sharp rise in the hardness and brittleness because of the formation of the sigma phase. At contents below 20 weight-percent rhenium, the plasticity of joint metal does not differ from that of unalloyed metal. This use of rhenium as an alloy addition to increase the plasticity of weld joints in molybdenum considerably widens the field of application of molybdenum as a structural material at relatively low consumption of rhenium.<sup>10</sup>

GTE Sylvania developed an improved process for the extraction of rhenium from molybdenum. The process employs solvent extraction for the separation and recovery of rhenium from sodium molybdate solutions obtained from molybdenite concentrate using a quaternary amine (Aliquat 336) as the extractant. The solvent system initially investigated was the decanol-kerosine system. However, rhenium extraction decreased with time, due to the formation of an insoluble amine-rhenium complex. As a result, the solvent system was replaced with a high-aromatic solvent (SC #28), and the rhenium extraction efficiency was found to be constant. Nitric acid was used as the stripping agent in both systems. A continuous countercurrent, mixer-settler extraction system was employed, and the concentrated rhenium solution was subjected to ion exchange for further purification and isolation.<sup>11</sup>

Rhenium has a unique effect on tungsten, molybdenum, and chromium, increasing strength and ductility, especially in the region of saturated solid solutions with body-centered cubic structure. This phenomenon, known as the "rhenium effect," was discovered in 1955 in England and was used to develop a range of alloys of tungsten and molybdenum with rhenium. Research was conducted on the rhenium effect through the structure and properties of the ternary Mo-Re-C system. It was found that one of the main reasons for the rhenium effect was the higher solubility of carbon in the saturated Mo-Re solid solution than in pure molybdenum, (about five times higher), and also the appearance of a new carbide having higher strength and plasticity than Mo<sub>3</sub>C in the Mo-Re alloy. The carbide is a solid solution of rhenium in molybdenum carbide. At 1,500° C, the solubility of carbon in the solid solution was about 0.05 weight-percent in Mo-95% Re alloy; 0.025 weight-percent in Mo-20% Re alloy; and less than 0.01 weight-percent in pure molybdenum.<sup>12</sup>

The effect of thermal cycling on the prop-

erties of Ta-Cb-Re alloys was studied. The addition of rhenium has a positive effect on increasing the thermocyclic resistance of tantalum and tantalum-columbium alloys. The effect was attributed to strengthening of the solid solution and increasing of interatomic forces.<sup>13</sup>

Two major improvements were made to Chevron Research Co.'s Rheniforming technology during the year. These were an improved catalyst called Type F, and a sulfur-control system. The main advantage of the Type F catalyst over previous catalysts reportedly is greatly increased stability which allows the reforming units to operate at higher octane, increased feed rate, or decreased pressure to increase yields without shortening run length. After regeneration, the catalyst can be returned to performance nearly identical to that of fresh catalyst. The catalyst was undergoing testing in 1977, and is scheduled to be in commercial service in late 1978. Use of the sulfur-control system showed a significantly higher yield and longer run lengths. Rates of return on investment for the system were in the 60% to 100% range for three operating units employing the system. Design and construction of nine more units at existing refineries were planned. Ten licensees will install the sulfur-control system, and new Rheniformers will include this technology as a standard part of the system.<sup>14</sup>

A new alloy of rhenium was developed for use as a cathode connector for a structural element subjected to mechanical load. The connector must have specific electrical properties, since voltage is applied through it across the cathode-anode circuit. The strength of the cathode connector can be increased by increasing its resistance to thermal cycles. The alloy consists of 50% iron, 40% nickel, and 10% rhenium. Because of its superior physical properties, this alloy reportedly has given good results in numerous test devices. Rhenium raises the recrystallization temperature of the alloy by 300° C, and the material has a finer grain size after recrystallization. Because of the finer grain size, grain growth in the connector material is limited during welding, the grain size in the alloy being 5 to 10 times finer even after prolonged tests and annealing at 600° C to 1,000° C. The addition of rhenium to the iron-nickel solid solution improved its mechanical properties by at least 1.5 times at the usual cathode temperatures. At temperatures above 300° C, the grain growth is checked, the strength

is greater at a given grain size, and softening takes place more gradually.<sup>15</sup>

Research continued on use of rhenium-bearing alloys as gas absorbers in electrovacuum devices. A titanium-rhenium alloy, in wire form used as a directly heated atomizable gas absorber in photoelectronic devices, had two advantages: The film obtained by evaporation of titanium when the absorber was heated to 1,330° C had sorptional activity with respect to hydrogen greater than that of barium absorbers used at present in photoelectronics; another advantage was its low coefficient of linear thermal expansion, which ensures constancy of shape of the absorber in use in the device. The main disadvantage was the embrittlement of the wire as titanium evaporates, which makes their use impossible in vibration-resistant devices.<sup>16</sup>

A patent was issued for the recovery of rhenium values from an aqueous sodium molybdate solution obtained in the hydrometallurgical processing of roasted molybdenite. The solution was contacted with a quaternary ammonium compound dissolved in at least 50 volume-percent of a highly aromatic solvent. The rhenium-enriched organic phase was separated and stripped of values, and the extractant solution was recycled.<sup>17</sup>

<sup>1</sup>Industry economist, Division of Ferrous Metals.

<sup>2</sup>Oil & Gas Journal. *Federals Shape U.S. Refining Industry*. V. 76, No. 12, Mar. 20, 1978, pp. 63-66.

<sup>3</sup>Oil & Gas Journal. *Analyzers Important in Cat Reforming*. NPRA 1977 Question and Answer Session. V. 76, No. 19, May 8, 1978, p. 258.

<sup>4</sup>Knipple, W. R. *Rhenium*. *Metals Bull.*, 1977 Minor Metals Survey.

<sup>5</sup>Margulis, R. B., E. M. Savitskii, M. A. Tylkina, and E. P. Arskaya. Paper in Russian (Use of Rhenium Alloys in Ultra-High Frequency Cermet Tubes). *Akademiya Nauk SSSR*, Moscow, 1975, pp. 181-188; English translation published for the U.S. Department of the Interior and the National Science Foundation, TT 76-52045, 1977, 343 pp.

<sup>6</sup>Metal Bulletin. Chile's Mo Place. No. 6221, Sept. 2, 1977, p. 25.

<sup>7</sup>Oil & Gas Journal. *Germany Sets Tough Pace for Other EEC Refiners*. V. 75, No. 49, Nov. 28, 1977, pp. 55-64.

<sup>8</sup>Scheiner, B. J., D. L. Pool, and R. E. Lindstrom. *Extraction and Recovery of Molybdenum and Rhenium From Molybdenite Concentrates by Electrooxidation: Prototype Cell Demonstration*. Pres. at Ann. Meeting of The Canadian Institute of Mining and Metallurgy (CIM), Vancouver, B. C., Aug. 21-25, 1977, 12 pp.

<sup>9</sup>Litz, J. E., and R. B. Coleman. *Recovery of Rhenium From Molybdenite Concentrates*. Pres. at Ann. Meeting of CIM, Vancouver, B. C., Aug. 21-25, 1977, 19 pp.

<sup>10</sup>Morozov, B. P., B. B. D'yachenko, V. I. Perezhogin, and A. A. Delezha. Paper in Russian (Use of Rhenium for Increased Plasticity of Weld Joints in Molybdenum Alloys). *Akademiya Nauk SSSR*, Moscow, 1975, pp. 312-318; English translation published for the Department of the Interior and the National Science Foundation, TT 76-52045, 1977, 343 pp.

<sup>11</sup>MacInnis, M. B., L. R. Quatrini, and T. K. Kim. *An Improved Solvent Extraction Process for the Separation of Rhenium From Molybdenum*. Pres. at Ann. Meeting of American Institute of Mining, Metallurgical, and Petroleum Engineers, Atlanta, Ga., Mar. 6-10, 1977, 19 pp.

<sup>12</sup>Savitskii, E. M., M. A. Tylkina, and L. Z. Konieva. Paper in Russian. (Mechanism of the Rhenium Effect). *Akademiya Nauk SSSR*, Moscow, 1975, pp. 43-53; English translation published for the U.S. Department of the Interior and the National Science Foundation, TT 76-52045, 1977, 343 pp.

<sup>13</sup>Savitskii, E. M., M. A. Tylkina, V. E. Alyushin, A. M. Levin, L. N. Potemina, E. V. Rudenskii, and T. V. Semenova. Paper in Russian (Effect of Thermal Cycling on the Properties of Ta-Cb-Re Alloys). *Akademiya Nauk SSSR*, Moscow, 1975, pp. 84-90; English translation published for the U.S. Department of the Interior and the National Science Foundation, TT 76-52045, 1977, 343 pp.

<sup>14</sup>Buss, W. C., R. L. Jacobson, F. H. Vorhis, and A. I. Salka. *New Developments in Rheniforming*. Pres. at Ann. Meeting of National Petroleum Refiners Association, San Antonio, Tex., Mar. 19-21, 1978, 20 pp.

<sup>15</sup>Iofis, N. A. Paper in Russian. (The Use of Rhenium in Electronics). *Akademiya Nauk SSSR*, Moscow, 1975, pp. 175-180; English translation published for the U.S. Department of the Interior and the National Science Foundation, TT 76-52045, 1977, 343 pp.

<sup>16</sup>Pages 179 and 180 of work cited in footnote 15.

<sup>17</sup>Quatrini, L. R., and M. B. MacInnis (assigned to GTE Sylvania, Inc., Stamford, Conn.). *Extraction Process for Recovery of Rhenium*. U.S. Pat. 4,049,771, Sept. 20, 1977.

