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A LITERATURE SEARCH AND ANALYSIS OF INFORMATION REGARDING SOURCES, USES, PRODUCTION, CONSUMPTION, REPORTED MEDICAL CASES, AND TOXICOLOGY OF PLATINUM AND PALLADIUM

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A LITERATURE SEARCH AND ANALYSIS OF INFORMATION REGARDING SOURCES, USES, PRODUCTION, CONSUMPTION, REPORTED MEDICAL CASES, AND TOXICOLOGY OF PLATINUM AND PALLADIUM

by

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EXECUTIVE SUMMARY

An intensive search of the literature provides the basis for the following conclusions concerning platinum and palladium

Supply and Demand. An average of 3.7 million troy ounces of platinum and palladium were produced in the world in the four-year 1969-1972 period. The United States consumed about a third of this. The proved world reserves amount to some 394 million troy ounces, with considerable promise of increasing these reserves through new explorations Half of the proved reserves are in the Republic of South Africa and 45 percent in the Soviet Union. Projected 1980 and 1990 world demands are 6 2 and 8.5 million troy ounces per year, respectively The introduction of a new demand for automotive emission control catalyst purposes (18 percent of the total in 1980 and 15 percent in 1990) is not expected to upset the world supply/demand situation

This assumption does not consider the possibility that other countries may adopt the catalytic muffler for their use If this occurs, there will be a larger demand on platinum and palladium resources Although it appears that the projected demands on platinum and palladium reserves can be met with known sources, it should be pointed out that the United States is almost completely dependent upon foreign sources. The United States currently consumes nearly 40 percent of the world production, but it produces less than 1 percent

Health Hazards. No data exist by which an estimate can be made of transfer of platinum and palladium to the environment Investigations show that only the salts of platinum present human health hazards Industrial exposure to these is limited to the mining and refining of platinum ores and the preparation of catalysts for the chemical and petroleum refining industries

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NARRATIVE SUMMARY

Present World Supply and Demand

Based on reasonably reliable estimates from foreign sources, world production of platinum and palladium is estimated to have increased from a total of 3.12 million troy ounces in 1969 to 3 90 million troy ounces in 1972, a four-year increase of 25 percent World production by source is summarized in the table below

WORLD PRODUCTION OF PLATINUM & PALLADIUM

Average Annual, 1969-1972
(Thousands of Troy Ounces)

Source	1969-1972 Average		
	Platinum	Palladium	Total
Canada	188	187	375
Colombia	26	-	26
Ethiopia	0 3	-	0 3
Finland	0 2	0 3	0 5
Japan	3	5	8
Philippines	0 6	1	1 6
Republic of South Africa	909	321	1230
U S S R	665	1339	2004
United States	9	13	22
TOTAL	1801	1866	3667

Sources: Minerals Yearbook and *Engineering and Mining Journal*

Half of world platinum and one-sixth of world palladium production comes from the Union of South Africa One-third of platinum and over two-thirds of palladium production is from the U.S.S.R. Canada produces about ten percent of both platinum and palladium, while the United States produces less than one percent of each South Africa, U.S S R., and Canada combined produce 98 percent of the world's platinum and palladium.

Consumption of the two metals in 1971 is estimated to have been 3.7 million troy ounces, with the United States using 37 percent of the total, as shown in the following table Japan used 20 percent, Russia 16 percent, and West Germany 12 percent All other consumption totaled 15 percent of the world total

Sales to United States users in the five-year 1967-1971 period averaged slightly less than 1 3 million troy ounces per year. Sales to specific industrial categories are shown in the following table

WORLD CONSUMPTION OF PLATINUM & PALLADIUM

1971
(Thousands of Troy Ounces)

Nation	Consumption
United States	1376
Japan	758
U S S R	589
West Germany	451
France	313
Italy	74
Canada	68
United Kingdom	49
Netherlands	33
Sweden	17
Switzerland	12
TOTAL	3740

Source: Minerals Yearbook.

PLATINUM AND PALLADIUM SALES TO U.S. INDUSTRY

1967-1971 Averages
(Thousands of Troy Ounces per Year)

Industry Category	Five-Year Average Annual Sales		
	Platinum	Palladium	Total
Electrical	97	389	486
Chemical	155	208	363
Petroleum Refining	184	9	193
Dental and Medical	23	56	79
Glass	49	5	54
Jewelry and Decorative	31	19	50
Miscellaneous	29	35	64
TOTAL	568	721	1289

Source: Minerals Yearbook.

Some 38 percent of total sales were to the electrical industry, the palladium (over half) being used chiefly in telephonic equipment and the platinum being used chiefly for switch gear manufacture The chemical industry purchased 28 percent of the total during the 1967-1971 period, chiefly for sulfuric and nitric acid manufacture The petroleum refining industry purchased 15 percent of the total mostly platinum, for use in the refining processes These three industry groups purchased 81 percent of the platinum and palladium sales during the five-year period World reserves of platinum and palladium were estimated in the 1970 *Mineral Facts and Problems* to be about 394 million troy ounces These reserves are equivalent to 105 years of supply at the

1971 rate of 3.7 million troy ounces per year Proved reserve figures are given in the table below. There are extensive exploration and investigation of other prospective producing areas which are not included in these totals.

WORLD RESERVES PLATINUM & PALLADIUM

1970 Estimates
(Thousands of Troy Ounces)

Nation	Reserves		
	Platinum	Palladium	Total
Republic of South Africa	142,400	50,200	192,600
U S S R	60,000	120,000	180 000
Canada	6,940	6,860	13,800
Colombia	5,000	–	5,000
United States	950	1,960	2,910
TOTAL	215,290	179,020	394,310

Source: *Mineral Facts and Problems, 1970*

Nearly half of total estimated reserves are in South Africa, with another 45 percent in the Soviet Union Canada, Columbia, and the United States account for only 5 5 percent

Future World Demand

A series of estimates has been made for future demand for platinum and palladium on the part of major consuming industries, both in the United States and elsewhere. High, low, and median estimates were made for consumption in 1980 and 1990 The following table gives the median value of projected demands and reflects the impact of new demands for automotive exhaust emissions control catalysts. The 1971 sales to industry figure is included for comparison This figure is some 5 percent lower than the U S consumption figure shown earlier, reflecting transfers to small countries, chiefly for trading and speculation

Catalyst use for automotive emissions control, 40 percent of the United States demand in 1980 and 37 percent in 1990, is not expected to impose a supply hardship in the foreseeable future The additional needs amount to 18 percent of total world demand in 1980 and 15 percent in 1990 Producer indications are that production can be increased as the demand increases. The 1970 proved reserves of 394 million troy ounces are equivalent to 46 years of supply at the estimated 1990 annual consumption rate of 8.5 million troy ounces

ESTIMATED FUTURE WORLD DEMAND PLATINUM & PALLADIUM

(Thousands of Troy Ounces per Year)

		Total Demand		
		1971	1980	1990
United States	base platinum	541	734	1044
	automotive catalysts	–	774	866
	total platinum	541	1508	1910
	base palladium	760	898	1095
	automotive catalysts	–	332	371
	total palladium	760	1230	1466
	total base	1301	1632	2139
	total automotive	–	1106	1237
	Total	1301	2738	3376
Rest of world	platinum	1283	1826	2703
	palladium	1163	1655	2450
	Total	2446	3481	5153
Grand total	platinum	1824	3334	4613
	palladium	1923	2885	3916
	Total	3747	6219	8529

Source: *Mineral Facts & Problems, 1970, A Look at Business in 1990* (a Summary of the White House Conference on the Industrial World Ahead, February 7-9, 1972), and SwRI

Environmental Considerations

Losses to the Environment Essentially, no data were found in published sources covering industrial rates of transfer of platinum and palladium to the environment If such transfer is labeled as "unaccountable losses" versus attrition (that known loss from catalyst poisoning, handling and the like), then some speculation may be made as to (1) the probable sources of unaccountable losses, and (2) some feel for the relative importance of these

Most platinum or palladium is used by industry in two forms (1) as a metal, pure or in alloy, fabricated, melted and cast, or used directly, or (2) as a platinum or palladium compound either in solution or not and applied, as for catalyst preparation, to a carrier or matrix

While process losses certainly occur among the industries using metallic platinum and palladium, there should be little or no loss entering the environment in the sense of a potential health hazard These industries include the electrical industry where precious metals are used for switch contacts, dental work, the glass industry where precious metal spinerettes are used in the production of glass fibers, and the jewelry and decorative industries

In the chemical and petroleum refining industries, there is probably some transfer of platinum or palladium to the product. However, the most probable site of potential loss of platinum and palladium to the environment, in one form or another in the chemical and petroleum refining industries, is at the point of preparation of catalysts rather than at the chemical plant itself As an example, mineral carriers are impregnated with a platinum compound such as chloroplatinate in manufacturing the catalyst for producing nitric acid The catalyst is then further processed in order to render the platinum elemental in form In these processes, there are opportunities for spillage, vapor entrainment, or other mechanisms for loss Of the 354 thousand troy ounces of platinum and palladium consumed in the chemical industry in 1971, the Bureau of Mines estimates an attrition rate of some 49 thousand ounces of platinum There are no data published with which this attrition can be apportioned to the categories of transfer to product, transfer to the environment, or other source of loss

In summary, with respect to industrial losses of platinum and palladium to the environment, it is felt that two groups can be identified as having the work potential for such losses which may become matters of health concern first, the obvious group including mining, processing, and refining of platinum and palladium, and second, those firms engaged in the preparation, regeneration, and recovery of platinum and palladium catalysts for use in the chemical and petroleum refining industries Estimates of the amount or concentrations of losses to the environment cannot be made on the basis of data currently available from the literature

Human Exposure Cases Platinum was felt to be relatively harmless until a report published by Hunter, Milton, and Perry in 1945 in which was documented an investigation of exposure among workers in four refineries In essence, it was found that the complex salts of platinum produced various symptoms in a high percentage of workers exposed These symptoms include asthma, eczematous lesions, and dermatitis On the other hand, exposure to metallic platinum or palladium, or the complex salts of palladium, has produced no apparent similar effects Accordingly, only the complex salts of platinum appear to present a health hazard

Toxicology. Metallic platinum and palladium are nontoxic and never give rise to occupational injury The oxides of platinum cause eczema of the hands and forearms and some lesions of the nails Dust and spray from the complex salts of platinum have been found to cause asthma after continued exposure Initial symptoms begin with repeated sneezing followed by a profuse running of the nose with a watery mucous discharge Later reactions which may develop include tightening of the chest shortness of breath, wheezing and blue facial coloration When a person exposed to platinum salts leaves the contaminated environment, symptoms clear with the exception of persistent coughing Some individuals exhibit a scaly red skin rash similar to an allergy reaction Blood checks, skin tests, or X-rays do not reveal any abnormalities leading to these symptoms Treatment generally consists of removal from exposure Precautions lie in minimizing exposure and maintaining allowable concentrations of soluble platinum salts in the atmosphere at less than 2 $\mu g/m^3$

Palladium salts commonly used are the chloride and the amminonitrite So far as is known, these do not constitute any human health threats However, laboratory exposure tests on animals show results of damage to the heart, kidneys, liver, and bone marrow Accordingly, close surveillance should be maintained on the use of palladium salts in industry

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APPENDIX A. LITERATURE SEARCH

1. Introduction

The platinum group metals are often referred to as platinoids and are comprised of platinum, palladium, iridium, osmium, rhodium, and ruthenium. Canada, the Republic of South Africa, and the U. S. S. R. are the main world suppliers. Small quantities of platinoids are derived from Colombia, Ethiopia, Finland, Japan, the Philippines, and the U. S.

Platinoids are found in nature (a) associated with nickel-copper minerals that occur in ultrabasic rocks, dunite and norite, and (b) in placer deposits. Nearly all of the Canadian production and most of the U. S. S. R. production are a byproduct of nickel-copper refining. The South Africa production comes from mines worked principally for the platinoids with nickel and copper recovered as coproducts and gold and chromium as byproducts. Ethiopia and Colombia derive their production from placer deposits, whereas Finland, Japan, and the Philippines produce small amounts of platinoids as byproducts of copper refining. Minute amounts are also produced in Papua New Guinea. The U. S. output comes either from placer mining or is derived in the refining of gold and copper. Fairly high platinum values were discovered during test drillings in western Australia and in north Aukland, New Zealand, but further sampling will determine the commercial potential of these finds. Prospecting in Southern Rhodesia has also uncovered significant occurrences.

In addition to primary platinoid production, the metal group's high costs have stimulated a substantial effort for secondary recovery from all forms of scrap and used equipment, wherever economically feasible.

The estimated world production of platinoids is shown in Table A-1.

Table A-1. Estimated World Production of Platinum Group Metals (million troy oz)

	1969	1970	1971	1972 (Prelim.)
Platinum	1.48	1.98	1.82	1.92
Palladium	1.64	1.92	1.92	1.98
Other	0.29	0.35	0.34	0.35
Total	3.41	4.25	4.08	4.25

Source: E/MJ, March 1973

These data indicate that platinum and palladium are by far the most abundant and the most important elements of this group. Metals of the platinum group are measured and traded in terms of troy ounces in the British system of weights. In the metric system, measurements are in kilograms (1 kg equals 32.15 troy ounces). Platinum group metals are commercially available in grades ranging from 99.8 to 99.999 percent purity. Platinum and palladium are available in the form of sponge, single crystals, powder, wire, sheet, foil, and rods. Platinum above 99.7 percent is normally considered as commercial grade. According to Federal regulations, an article of trade may be marked platinum if it contains 98.5 percent platinum-group metals with a minimum of 93.5 percent platinum.

Most platinoids are recovered as byproducts of the milling, smelting, and refining of nickel and copper materials. In the Canadian Sudbury district, sulfide ore is processed by magnetic and flotation techniques to yield concentrates of copper and nickel sulfates. The nickel flotation concentrate is roasted with a flux and melted into a matte which is cast into anodes for electrolytic refining from which the precious metal concentrate is recovered. The platinum, palladium, and gold in the concentrate are dissolved with aqua regia, leaving a residue containing the remaining four platinoids. After the gold has been removed from the solution with ferrous sulfate, platinum is precipitated with ammonium chloride. Palladium may be precipitated as a chloride by the addition of excess ammonia and hydrogen chloride. The chloride of platinum and palladium are separately reduced to sponge metal which can be compacted and melted to massive metal. Byproduct platinoids from gold or copper ores are sometimes refined by electrolysis and by chemical means.

Milling and beneficiation of the platinum-bearing nickel ores from South Africa consist of gravity concentration, flotation, and smelting which produces a high-grade table concentrate called "metallics" for direct chemical refining and a nickel-copper matte for smelting and refining. The process of extraction consists essentially of enriching the nickel-copper matte to about 65 percent platinum metals and then treating the enriched product with acids to separate the individual platinoids, followed by final refining.

The mining of crude platinum in placer deposits furnishes a small part of total production. The mining and processing techniques for recovering crude platinum from placers are similar to those used for recovering gold.

The industrial applications for platinum and palladium are diverse. Platinum-group metals find application in the U. S. in the chemical, petroleum, glass, electrical, dental and medical, and jewelry and decorative industries.

Platinum-group metal producers, in general, experienced overproduction and idle capacity which lasted from 1970 to 1972. Renewed growth is expected, particularly for platinum and palladium to be used in automobile emission control systems scheduled to be installed from 1975 on. In addition to obtaining the required performance characteristics of these automotive catalytic converters, lead content in gasoline must be reduced and sulphur and phosphorus content must be limited to avoid rendering the platinum catalysts ineffective. It has been estimated that each car will require an average of 0.1 oz of platinum-group metals, including 30-35 percent palladium, with platinum comprising the balance. The relatively high costs of platinum and palladium have initiated intensive research into the use of suitable substitute catalysts. Thus, while the growth of supply is resuming at a steady pace, the utilization of increased output is precariously dependent on the development and final timing in the auto emission control area on a worldwide basis.

2. Platinum and Palladium Sources

The platinoid industry in the free world is centered about two major mining companies and two affiliated refining and fabricating companies. The International Nickel Co. of Canada, Ltd. (INCO) produces refined platinum-group metals as byproducts of its nickel-copper ore mining and refining operations in Canada, and accounts for about one-third of the free world output of these metals.

Rustenburg Platinum Mines, Ltd., Republic of South Africa, produces platinum-group metals from ores mined chiefly for platinum and contributes about two-thirds of the free world output of platinoids.

The refining and fabricating companies are Engelhardt Industries, Inc., Newark, N.J. affiliated with INCO and Johnson, Matthey & Co., Ltd. in Great Britain and their worldwide subsidiaries, affiliated with Rustenburg.

In addition to these major companies in mining, as well as refining and fabricating, a number of smaller organizations are engaged in these same activities in various countries as will be shown below; the level of their activities depends to a great extent on the world demand and supply.

A third major source of platinum and palladium in the total world market is the U. S. S. R. Little information is available on her industry pattern.

Canada. The Sudbury region of Ont. and the Thompson-Wabowden area of Man. are the major sources of Canadian production, derived in a residue at nickel refineries. A small amount of platinum metals is recovered from ores at Shebandowan, Ont. by INCO, in Que. by Renzy Mines Ltd., and near the Ont.-Man. boundary by Consolidated Canadian Faraday Ltd. and Dumbarton Mines, Ltd.

Canadian production in 1972 was 399,000 troy ounces compared with 475,169 ounces in 1971. Cutting back in nickel-copper production by INCO during this time period is the principal factor for the decline in Canadian platinoid production.

In Ont., INCO as the largest producer, operated 13 nickel-copper mines, four concentrators, and two nickel-copper smelters near Sudbury, Ont. in 1972. A new nickel refinery was also being tuned up, where platinoid-bearing residues will be recovered. The Coniston Smelter and Totten and Crean Hill mines were temporarily closed, and production was reduced at several other operations in early 1972. Development work is continuing at INCO's Levack West mine scheduled for production in 1975. In Ont., INCO operated a nickel refinery at Port Colborne and started mining the Shebandowan deposits.

Falconbridge Nickel Mines, Ltd. operated eight nickel-copper mines, four concentrators, and one smelter in the Sudbury region in 1972. Their Longvack South mine was temporarily closed. Consolidated Canadian Faraday, Ltd. closed its Werner Lake mine because ore reserves were exhausted.

In Que., Renzy Mines, Ltd. closed its nickel mine and concentrator when the company's smelter contract expired.

In Man., INCO operated three mines, one concentrator, and a smelter-refinery complex at Thompson. Falconbridge had a normal year of operations at its Manibridge mine and concentrator near Wabowden. Dumbarton Mines, Ltd. which ships nickel-copper concentrate to the Falconbridge smelter, increased ore production from 700 to 1100 tpd.

INCO's crude platinum-metal-bearing residues are initially concentrated in Canada and then shipped to INCO's Metals Refinery at Acton, London, England for extraction and refining of the platinum metals. Much of the refined metals are returned to Canada and exported to the United States for fabrication and distribution by Engelhard Industries, Inc. Newark, N. J.

Falconbridge ships nickel-copper matte containing precious metals to its nickel refinery in Kristiansand, Norway from which platinoid-bearing residue also goes to Engelhard for further refining.

Republic of South Africa is the free world's largest producer of platinoids. Rustenburg Platinum Mines, Ltd. (RPM) operates three mines, one smelter and a refinery in the Transvaal district. Rustenburg increased capacity to 1.1 million ounces of platinoids a year, but reduced production in 1971 to about 500,000 ounces because of excessive inventory accumulations. As prospects for a new market are good, the opening of a new mine and an increase of production to 1.3 million ounces a year are planned.

Impala Platinum Ltd. operates a mine-concentrator-refinery complex near Rustenburg. Capacity at the operation is 350,000 ounces of platinum a year, and current production is at an annual rate of about 300,000 ounces. Impala has also announced plans to expand its facilities.

Atok Investments (Pty.) Ltd., producing at Anglovaal and Middle Witwatersrand made its first shipment of a platiniferous concentrate and matte from the Middlepunt mine in 1970 and produced an estimated 10,000 ounces of platinoids.

The Lonrho Ltd.-Falconbridge Nickel Mines Ltd.-South Africa Superior Oil Co. consortium formed Western Platinum Ltd., which commenced production at its Middlekraal mine near Rustenburg in 1971. The operation has an annual capacity of 150,000 ounces of platnoids. Annual capacity may be increased to 430,000 ounces of platinoids by 1974-75, and the company is considering construction of a platinum refinery near the mine.

Platinum group metal production statistics are not reported in South Africa. In 1970, RPM accounted for an estimated 83 percent of total output, and Impala produced most of the remainder. An estimate of the platinoid growth potential is shown in Table A-2.

U.S.S.R. - The U.S.S.R. is the second largest producer of platinum-group metals in the world.

Most of the production of platinum-group metals comes from nickel-copper ores of the Norilsk region in northwestern Siberia. Palladium accounts for about 60 percent of this production and platinum for 30 percent. Nickel-copper ores in the Kola Peninsula also contribute to the output of these platinoids. Placer platinum deposits in the Ural mountains, which at one time yielded most of the platinum produced in the U.S.S.R., now contribute only a small part of the overall output. Presently, the U.S.S.R. is by far the largest producer of palladium, and ranks second after the

Table A-2. Growth Potential for South African Platinum and Palladium
(1000 troy oz)

	1972	1973	1974	1975
Platinum				
Rustenburg	550	900	1,300	1,500
Impala	345	400	500	650
Western Platinum	93	125	160	200
Atok	12	15	30	200
Total Platinum	1,000	1,440	1,990	2,550
Total Palladium	355	550	700	890

Source: E/MJ, March 1973

Republic of South Africa in production of platinum. As official U.S.S.R. output figures are not available, it is estimated that the U.S.S.R. is currently producing platinum group metals at an annual rate of well over 2.2 million oz of which over half is palladium. The U.S.S.R. is supplying 20 to 25 percent of international exports of platinum and 70 to 75 percent exports of palladium.

Colombia is the fourth largest producing country. Crude platinum is recovered largely as a coproduct of gold; it is marketed in the U.S. through various dealers and refiners. Although placer deposits contain substantial reserves of platinum, some areas are not easily accessible and the contained platinum may not be economically recoverable. Colombia's platinum production has declined for several years and currently is about 25,000 oz annually.

Ethiopia. Explorations for platinum, copper and petroleum deposits by private industrial firms and the Ethiopian Geological Society are continuing. Placer platinum is retrieved in the vicinity of Gambela, Ilubabor Province.

Finland. Platinum-group metals are recovered as byproducts from the copper refinery at Pori, owned by Outokumpu Oy.

Japan. In 1970, Japan has produced 47,000 oz of platinoids, mostly platinum and palladium, as byproduct of nickel-copper refining, all of which were exported to Mainland China, the United States and West Germany.

The Philippines. Platinum-group metals, mostly platinum and palladium, come from the nickel-cobalt concentrates of Acoje Mining Co. at Santa Cruz, Zambales Province, Luzon. The concentrate, which is 15 percent nickel-cobalt, assays 1.4 ounces of platinum and 2.8 ounces of palladium per ton of concentrate.

United States of America. The major part of the U.S. output is recovered as a byproduct of copper refining in Maryland, New Jersey, Texas, Utah, and Washington. A small part of domestic output is recovered from a placer platinum deposit at Goodnews Bay, Alaska; this output is purchased by Johnson, Matthey & Co. and refined by its affiliate, Matthey Bishop, Inc. Malvern, Pa. U.S. refiners also process imported materials such as crude platinum from Colombia and platinum bearing nickel-copper matte from the Republic of South Africa. In addition, the refiners purchase platinum- and palladium-bearing scrap, residues, catalysts, and other platinum-bearing materials. Secondary recovery and toll refining are important segments of this industry. In 1970, the refinery production of new metal in the U.S. was 21,395 oz, and of secondary metal 349,126 oz; the total industry consumption was 1,335,467 oz.

Summary of Sources

Canada, Ont.:

International Nickel Company of Canada, Ltd.
Ontario Division
Copper Cliff, Ont. Canada (705/682-4411)
Location: Sudbury District
President and General Manager: G. McCreedy
Employment: 36,089 total

Coniston Smelter
Copper Cliff, Ont., Canada
Manager of Smelters: J.N. Lilley

Levack West Mine
Copper Cliff, Ont. Canada
Area Superintendent: D. Lennie

Port Colborne Refinery
Copper Cliff, Ont. Canada
Manager: W.V. Barker
Employment: 2,200

Shebandowan Mine
Copper Cliff, Ont. Canada
Manager: G.W. Johnston

Copper Refinery
Copper Cliff, Ont., Canada
Manager: G.A. Dick

Falconbridge Nickel Mines, Ltd.
Headquarters: P.O. Box 40, Commerce Court West
Toronto 1, Ont. Canada (416/863-7000)
President and Managing Director: Marsh A. Cooper
Employment: 4049 total

Sudbury Operations Headquarters:
Falconbridge, Ont. Canada (705/693-2761)
Sudbury Operations General Manager: G.A. Allen

Canada, Man.

International Nickel Company of Canada, Ltd.
Manitoba Division
Thompson, Man. Canada (204/677-5211)
President and General Manager: D.E. Munn
Employment: 3,700

Falconbridge Nickel Mines, Ltd.
Mainibridge, Man. Canada (204/689-2413)
General Manager: W.A. Case
Employment: 190

Dumbarton Mines, Ltd.
Headquarters: 1600, 100 Adelaide St. West
Toronto, Ont. Canada

Mine
Maskwa Lake, Man. Canada
Concentrator Superintendent: K. Dixon
Mine Superintendent: C.P. Moore

Republic of South Africa

Rustenburg Platinum Mines, Ltd.
Rustenburg and Union Sections
Consolidated Bldg., P.O. Box 590
Johannesburg, Trvl., S. Africa
General Manager: J.S. Ritchie
Manager, Rustenburg Section: J.C.J. Van Rensburg
Manager, Union Section: F.J. Brown
Employment: 26,000 total

Impala Platinum Ltd.
3rd floor, Unicorn House, 70 Marshall St.
P. O. Box 61386, Marshalltown
Johannesburg, Trvl, S. Africa (834-4552)
Managing Director: K. A. B. Jackson
Employment: 10,000 total

Bafokeng Mine
P. O. Box 363, Rustenburg, Trvl., S. Africa
Telephone: Rustenburg 2616
Mine Manager: R. C. Bovell
Employment: 9,500

Refineries
P. O. Box 222, Springs, Trvl., S. Africa
Telephone: Springs 56-6777
Chief Engineer: H. W. Read
Manager Platinum Refinery: P. A. Reynolds
Employment: 500

Western Platinum Ltd.
Rustenburg, Trvl., S. Africa

New Plants

Atok Investments (Pty) Ltd.
c/o Anglovaal House, 56 Main St., P. O. Box 62379
Marshalltown,
Johannesburg, Trvl., S. Africa

New Plants

Klockner Werke of West Germany
c/o Rand Mines Limited
The Corner House 63, P. O. Box 62370
Marshalltown
Johannesburg, Trvl., S. Africa

Exploration

U. S. S. R. All enterprises are owned and run by the communist government.

No detailed data are published outside Russia.

Colombia:

Cia Minera Choco Pacifico, S. A.
Andagoya, Istmina Choco, Colombia
Manager: Jaime Zapata
Employment: 438

Cia Minera de Narino, S. A.
Barbacoas, Narino, Colombia
Manager: Carlos Aspillera
Employment: 192

International Mining Corporation
280 Park Avenue
New York, N. Y. 10017 (212/983-7500)
President: Patrick H. O'Neill
(Pato Consolidated Gold Dredging Ltd.
Aparto Aereo 13-06, Medellin, Colombia
General Manager: Edward Moseley-Williams
Employment: 455)

The Philippines

Acoje Mining Co. Inc.

2283 Pasong Tamo Extension
Makati Rizal, Philippines (89-35-61)

Nickel Project
Santa Cruz, Zambales, Philippines
Mine Superintendent: Elmer B. Gabaldow
Employment: 130

Finland

Oytokumpu
Toolonkatu (Box 10280)
Helsinki (10) Finland

Pori Works
Pori, Finland (Pori 11701)
Works Manager: Aarne Kapanen
Employment: 2000

Australia: Possible future platinum operations.

Matthey Garret Pty, Ltd.
P. O. Box 165, Kogarah
New South Wales 2217

New Zealand: Possible future platinum operations.

Matthey Garret (NZ) Ltd.
22 Drake St., P.O. Box 2073, Auckland

United States of America

Goodnews Bay Mining Co.
(422 White Bldg., Seattle, Wash. 98101)
Platinum, Alaska 99651
Vice President and General Manager: Edward Olson
Employment: 47

American Smelting and Refining Company
Baltimore Plant, Highland and Eastbourne Aves.
Baltimore, Md. 21224 (301/675-0090)
Manager: R. H. Funke, Jr.
Employment: 1,200

United States Metals Refining Co.
440 Middlesex Ave., Carteret, N. J. 07008
(201/541-4141)
General Superintendent: Robert N. Brown
Employment: 1,800

Phelps Dodge Refining Corporation
El Paso Refinery, P. O. Box 2001
El Paso, Texas, 79998 (915/772-2701)
Vice President and Works Manager: M. S. Bell
Employment: 880

American Smelting and Refining Company
Tacoma Plant, P.O. Box 1677
Tacoma, Washington, 98401 (206/759-3551)
Manager: R.E. Shinkoskey
Employment: 1,000
(Company does custom smelting; verification of platinoid smelting necessary)

Kennecott Copper Corp. Metal Mining Division
Utah Copper Div., P.O. Box 11299
Salt Lake City, Utah 84111 (801/322-1533)
General Manager: J.P. O'Keefe
Employment: 7,200
(Verification of platinoid smelting necessary)

3. Platinum and Palladium Processors

It was stated earlier that the platinum-group metals industry in the free world is essentially centered around two mining companies and two affiliated refining and fabricating companies. The major refining and fabricating companies processing mainly new platinoid materials (Engelhard and Johnson Matthey) are not mining companies and are, therefore, not vertically integrated. Imports of platinum-group metals include refined metals (90%), unrefined metals, crude ores and concentrates, grain, nuggets and residue. U.S. exports of platinum group metals, principally as semi-processed metals and alloys and as manufactured products are small compared with imports. Secondary recovery and toll refining comprise the bulk of domestic refining operations. In 1968 (latest figure available) 2.3 million troy ounces were produced by toll refining operations, of which 91 percent represented used material and 9 percent was metal recovered from virgin material. As it is not possible to separate this intertwined industry clearly by functions like mining, refining, fabricating, etc., the following lists show first the key members of this industry (Group I) followed by those emphasizing refining (Group II) and finally those emphasizing fabricating (Group III). In reality, some companies may be active in all areas and some only in segments of this industry. Companies listed are those with over $500,000 total assets. Some may be brokers only. This cannot be avoided as many of the specialized companies are not listed in Standard & Poor's Register.

U.S.	Canada
Group I: Key members	
Engelhard Industries Division (Engelhard Minerals and Chemicals Corp.) 430 Mountain Ave. Murray Hill, N.J. 07974 (201/464-7000) Executive Vice President: Robert S. Leventhal Employment total: 7,500	Engelhard Industries of Canada, Ltd. 512 King St. E. Toronto 2, Ont. (416/362-3211)
Matthey Bishop, Inc. Malvern, Pa. 19355 (215/644-3100) Vice President Operations: H.S. Roberts Also: Johnson Matthey & Co., Inc., 608 Fifth Avenue, New York, N.Y. 10020 (212/245-6790), representative of parent company, Johnson Matthey & Co., Ltd., 78 Hatton Garden, London, E.C. 1, England (01-405-6989)	Johnson Matthey & Mallory, Ltd. 110 Industry St. Toronto 15, Ont. (416/763-5111)
Group II: Refiners	
Handy and Harman 850 Third Avenue New York, N.Y. 10022 (212/752-3400)	Handy and Harman of Canada, Ltd. 141 John Toronto 20 Ont.
American Chemical and Refining Co. P.O. Box 4067 Waterbury, Conn.	National Refining Co., Ltd. 136 St. Patrick Toronto (w)

U. S.	Canada
National Lead Co. Goldsmith Division 1300 W. 59th St. Chicago, Ill.	
United Refining & Smelting Co. 3700-20 N. Runge Ave. Franklin Park, Ill. 60131 (312/455-8800)	
Hyperrefiners, Inc. P.O. Box 80-T Clifton, N.J.	
Engelhard Minerals & Chemicals Corp. 429 Delaney St. Newark, N.J. 07105	Engelhard Industries of Canada, Ltd. 512 King St. E Toronto 2, Ont. (416/362-3211)

Eastern Smelting and Refining Corp.
35 Bubier Street
Lynn, Mass (617/599-4000)

Selrex Corp
Precision Metals Recovery Division
73 River Road
Nutley, N.J.

Spiral Metal Co.
South Broadway
South Amboy, N.J.

Sabin Metal Corp
310-334 Meserolf St.
Brooklyn, N.Y. 11206 (212/381-5000)

Samuel J. A. & Co., Inc.
233 Broadway
New York, N.Y. 10007

Midland Processing, Inc.
53 Lafayette Ave.
White Plains, N.Y. 10603 (914/949-9310)

Mercer Refining
2801-T W Lake
Melrose Park, Ill.

Group III: Fabricators

Western Gold & Platinum Co.
555 Harbor Blvd.
Belmont, Calif.

Whittaker Corp.
10880 Wilshire Blvd.
Los Angeles, Calif.

Wildberg Bros. Smelting & Refining Co.
349 Oyster Point Blvd.
South San Francisco, Calif.

U. S.	Canada
Ney, J.M. Co. Drawer 990 Hartford, Conn. 06101	
duPont, E.I. de Nemours & Co., Inc. Wilmington, Del.	
National Lead Co. Goldsmith Div. 1300 W. 59th St. Chicago, Ill. 60636 (312/925-3800)	
United Refining & Smelting Co. 3700-20 N. Runge Ave. Franklin Park, Ill. 60131 (312/455-8800)	
Mercer Refining 2801-T W. Lake Melrose Park, Ill.	
Texas Instruments, Inc. 30 Forest Attleboro, Mass.	
Eastern Smelting & Refining Corp 35 Bubier St. Lynn, Mass. 01901 (617/599-9000)	
Engelhard Minerals & Chemicals Corp 113 Astor St. Newark, N.J. 07114 (201/242-2700) President: Milton F. Rosenthal Employment: 7,500 total	Engelhard Industries of Canada, Ltd. 512 King St. E. Toronto 2, Ont. (416/362-3211)
Spiral Metal Co. So. Broadway So. Amboy, N.J. 08879	
Sabin Metal Corp. 310-334 Mescrole Brooklyn, N.Y.	
Williams Gold Refining Co., Inc. 2960 Main Buffalo, N.Y.	
Aderer, J. Inc. 44th Ave. & 22nd Long Island City, N.Y.	
Consolidated Refining, Inc. 120 Hoyt Ave. Mamaroneck, N.Y.	
American Metal Climax, Inc. 1270 Ave. of the Americas New York, N.Y.	
Anaconda Co. 25 Broadway New York, N.Y.	

U.S.	Canada
Copper Joseph B. & Sons, Inc. 178 Varick New York, N.Y.	
Handy & Harman 850 Third Ave. New York, N.Y.	Handy and Harman of Canada, Ltd. 141 John Toronto 20, Ont.
Phillip Brothers Div. 299 Park Ave. New York, N.Y.	
Samuel, J.A. & Co. 233 Broadway New York, N.Y.	
United Mineral & Chemical Corp Hudson & Bach St. New York, N.Y.	
Midland Processing, Inc. 53 Lafayette Ave. White Plains, N.Y.	
Secon Metals Corp 5-7 Intervale White Plains, N.Y.	
Buckeye Molding Co. Crysteco Div. 181 E. Main Wilmington, Ohio	
Technic, Inc. P.O. Box 965 Providence, R.I.	
American Chemical & Refining Co. Inc. P.O. Box 4067 Waterbury, Conn.	
Deringer Metallurgical Corp. 1252 E. Town Line Rd. Mundelen, Ill.	
Kron J. Williams Co. Inc. 301-303 Veteran Blvd. Carlstadt, N.J.	
Hamos Co. 242 W. 30th New York, N.Y.	

4. Prominent Sources and Processors

In the U.S., most platinoids are byproducts from copper and gold refining and, therefore, these types of companies are shown as representative sources. Processors (refiners and fabricators) are those that may include refineries specifically for platinoids and thus direct human exposure to platinum and palladium is expected to be much stronger during processing than during copper and gold refining.

Prominent Sources (for details see pages A-4 through A-7). Most Canadian concentrates, residues and matte are sent to England and Norway for refining or processing.

U. S.

American Smelting & Refining Co.

United States Metals Refining Co.

Phelps Dodge Refining Corp.

American Smelting and Refining Corp.

Kennecott Copper Corp.

Good News Bay Mining Co.

Canada

International Nickel Comp. of Canada, Ltd.

Falconbridge Nickel Mines, Ltd.

Dumbarton Mines, Ltd.

Prominent Processors:

Engelhard and Matthey Bishop are the most prominent and established platinoid companies, with Engelhard having several divisions dealing in various platinoid applications. In other companies, particularly the larger and diversified ones, the number of employees may be misleading, as only a relatively small number of employees may deal with platinum and palladium.

U. S.

Engelhard Minerals & Chemicals Corp.
Baker Platinum Division
700 Blair Road, Carteret, N.J. 07008

Chemicals & Catalysts: Engelhard Industries
Division of Engelhard Minerals &
Chemicals Corp
429 Delaney, Newark, N.J.

Engelhard Industries
Division of Engelhard Minerals &
Chemical Corp.
430 Mountain Ave.
Murry Hill, N.J. 07974 (201/464-7000)
Executive Vice President: Robert S. Leventhal
Employment: 7,500

Matthey Bishop, Inc.
Malvern, Pa. 19355 (215/644-3100)
Vice President Operations: H.S. Roberts

Handy & Harman
850 Third Ave.
New York, N.Y. 1022 (212/752-3400)
Vice President R&D: C.D. Coxe
Employees: 2,200

Eastern Smelting & Refining Corp.
37-39 Bubier
Lynn, Mass. 01903 (617/599-9000)
President: Jordan L. Alperin
Employees: 50

Canada

Engelhard Industries of Canada, Ltd.
512 King St. E.
Toronto 2, Ont. (416/362-3211)

Johnson Matthey & Mallory, Ltd.
110 Industry St.
Toronto, 15, Ont. (416/763-5111)

Handy & Harman of Canada, Ltd.
141 John
Toronto 21, Ont.

U.S.	Canada

N. L. Industries, Inc.
Goldsmith Division
1300 W. 59th St.
Chicago, Ill. 60636 (312/925-3800)
General Manager: Albert Dipiazza, Jr.
Employees: 160

Consolidated Refining Co. Inc.
120 Hoyt Ave.
Mamaronek, N.Y. 10543 (914/698-2300)
President: Mortimer M. Cass
Employees: 130

Segrex Corp, Subsidiary
Hooker Chemical Corp.
Precious Metals Recovery Division
73 River Road
Nutley, N.J. 07110 (201/667-5200)
Vice President Research: D. Bruce Merrifield
Employees: 10,000 total

Western Gold & Platinum Co.
(Subs. GTE Sylvania)
555 Harbor Blvd.
Belmont, Calif. 94002 (415/593-3121)
Vice President Manufacturing: Harold O. Richter
Employees: 280

J. M. Ney Co.
Drawer 990
Hartford, Conn. 06101 (203/242-2281)
Production Manager: Ronald G. Robinson
Employees: 300

5. Manufacturers of Automotive Emission Control Systems

U.S.

Engelhard Minerals & Chemicals Corp.
Matthey Bishop, Inc.
Universal Oil Products
W. R. Grace
Airproducts Division of Linde Products Company (Fecor Industries, Ltd.)

Japan

American Cyanamid and Japan Catalytic International

Europe

Deguzza (VW)
French Company (name unknown)
Engelhard Kali-Chemie Autocat G.M.B.H. (West Germany)

6. Production Data

World production of platinum and palladium by country are shown in Tables A-3 and A-4 below. It should be noted that official data--where available--are usually 2 years behind in publication. All South African figures are estimates, as no data are published on this industry.

World production expanded greatly in 1970, but demand failed to live up to expectations, partly because of the influence of business recession in the leading consumer countries. In early 1971, producers were forced to halt expansion projects and to cut back production. As a result, world

Table A-3. Platinum Production by Country
(troy oz)

Country	Year 1969	1970	1971	1972 (Est.)
Canada	134,715	209,374	203,112	(205,000)
Colombia	27,805	26,358	25,610	(24,000)
Ethiopia	343	273	217	(250)
Finland	---	295	275	(250)
Japan	3,140	3,296	3,451	(3,000)
Philippines	---	352	900	(1,000)
South Africa	676,400	1,068,000	890,000	(1,000,000)
U.S.S.R.	630,000	660,000	690,000	(678,500)
United States	8,702	8,036	10,198	(8,000)
World Total	1,481,105	1,975,984	1,823,763	(1,920,000)

Source: Minerals Yearbook 1971 and E/MJ, March 1973.

Table A-4. Palladium Production by Country
(troy oz)

Country	Year 1969	1970	1971	1972 (Est.)
Canada	133,163	206,962	200,772	(208,000)
Colombia	---	---	---	---
Ethiopia	---	---	---	---
Finland	---	350	325	(375)
Japan	3,877	4,610	5,381	(5,600)
Philippines	---	878	1,800	(2,000)
South Africa	238,450	376,500	313,750	(355,000)
U.S.S.R.	1,260,000	1,320,000	1,380,000	(1,397,000)
United States	8,387	11,875	20,951	(12,025)
World Total	1,643,877	1,921,175	1,922,979	(1,980,000)

Source: Minerals Yearbook 1971 and E/MJ, March 1973.

output slipped in 1971. That trend was again reversed with auto industry developments. Expansion plans resumed again early in 1972, and it is estimated that the 1972 output reached the previous high of 1970. The most active growth in the free world occurs in South Africa where platinum output may be boosted to upwards of 1.4 million oz in 1973 and further in 1974 and after, if the confidence in the auto demand outlook is unshaken. Some output recovery may be seen in Canada, although the long-term trend is relatively static.

7. Consumption Data

It was noted earlier that official data are published usually with a two year delay. Hence, the U.S. consumption data are now available for the year 1971.

United States. During 1971, the total sales of platinoids to the chemical, petroleum and electrical industries accounted for 83 percent of all sales compared with 82 percent in 1970. Platinum sales decreased slightly despite the 25-percent increase in sales to the petroleum industry and gains in sales for dental, medical and miscellaneous uses. The increase in sales to the petroleum industry was for new reforming units to produce non-leaded gasoline. The bulk of platinum sales in 1971 was distributed among petroleum refiners (46.5 percent), manufacturers of organic and inorganic chemicals (25.0 percent), and electrical and electronic equipment manufacturers (9.6 percent). Palladium sales increased 3 percent in 1971 despite sizable declines in sales to the glass industry. Sales to manufacturers of chemicals increased 18 percent, to manufacturers of electrical equipment 1 percent and accounted for 29 and 57 percent, respectively, of all palladium sales. Table A-5 shows the sales of platinum and palladium to consuming industries in totals, and Table A-6 and Table A-7 show sales to industry groups.

Table A-5. Platinum and Palladium Sold in the United States (troy oz)

Year	Platinum	Palladium
1967	633,864	621,141
1968	580,155	721,479
1969	515,578	758,738
1970	566,369	739,343
1971	541,164	760,106

Source: Minerals Yearbooks.

Table A-6. Platinum Sold to Consuming Industries in the United States (troy oz)

Industry	1967	1968	1969	1970	1971
Chemical	159,384	157,677	175,436	148,289	135,112
Petroleum	245,560	161,050	58,602	202,015	251,876
Glass	45,150	47,935	63,350	46,687	40,703
Electrical	99,686	117,256	112,589	103,318	51,940
Dental and Medical	24,630	24,903	22,266	18,302	23,097
Jewelry and Decorative	33,342	40,184	36,161	29,203	18,577
Miscellaneous	26,112	31,150	47,174	18,555	19,859
Total U.S. (re-revised)	633,864	580,155	515,578	566,369	541,164

Source: Minerals Yearbooks.

Table A-7. Palladium Sold to Consuming Industries in the United States (troy oz)

Industry	Year 1967	1968	1969	1970	1971
Chemical	192,011	228,318	214,508	184,618	218,651
Petroleum	3,506	22,683	1,337	15,494	2,916
Glass	301	10	3,891	21,147	237
Electrical	324,684	329,012	430,258	429,032	431,505
Dental and Medical	56,085	61,636	52,326	47,583	61,594
Jewelry and Decorative	18,676	17,797	21,837	17,329	18,752
Miscellaneous	25,878	62,023	34,581	24,140	26,451
Total U.S.	621,141	721,479	758,738	739,343	760,106

Source: Minerals Yearbooks.

Consumption data of countries outside the United States are difficult to assess, as trade data for each individual country would be needed. These are not readily available. The Rustenburg group has provided some estimates for the distribution of demand among the total Western world for newly mined platinum. These estimates are based on data for the period of 1965-69. As secrecy shrouds platinoid data in some producing countries, the following figures, developed for 1971, can be considered as only an overview of a complex and highly intermeshed demand-supply relationship for platinoid using countries. The Rustenburg data estimated that 30 percent is distributed to the chemical industry, 25 percent to petroleum catalytic uses, 20 percent to electrical and allied industries, 10 percent to glass manufacture, and the remaining 15 percent are distributed among various uses including jewelry and medical applications.

The total new world production during 1971 in platinoids was 4,076,788 ounces troy of which 1,823,763 oz were platinum and 1,922,979 oz were palladium. Free world demand distribution for new platinum and palladium metals is shown in Tables A-8 and A-9. The industry distribution is based on U.S. 1971 data as shown in Tables A-6 and A-7, with Rustenburg estimates for platinum given in parentheses. The Rustenburg data differ widely with the U.S. distribution in most industrial categories. It should be expected that the demand distribution in most industrialized nations of the Free World follow more closely the U.S. pattern. As Rustenburg assumes an authoritative position in this metals industry, the actual demand distribution may be between both limits.

Table A-8. Free World Platinum Demand Distribution
(troy oz)

Total 1971 world production		1,823,763
U.S.S.R. estimated total 1971 production		690,000
U.S.S.R. estimated 1971 export		336,375
U.S. new 1971 production		10,198
Free World available new production		1,459,940
Estimated demand distribution		
Chemical industry (25 percent)	364,985	(473,852)
Petroleum industry (46.5 percent)	678,872	(394,876)
Glass industry (7.5 percent)	109,496	(157,951)
Electrical industry (9.6 percent)	140,154	(315,901)
Dental and medical industry (4.3 percent)	62,777	
Jewelry and decorative industry (3.4 percent)	49,638	(236,926)
Miscellaneous (3.7 percent)	54,018	

Source: Minerals Yearbook 1971, Universal Facts and Problems 1970 and Southwest Research Institute.

Table A-9. Free World Palladium Demand Distribution
(troy oz)

Total 1971 world production		1,922,979
U.S.S.R. estimated 1971 production		1,380,000
U.S.S.R. estimated 1971 export		1,009,125
U.S. new 1971 production		20,951
Free World available new production		1,531,153
Estimated demand distribution		
Chemical industry (28.8 percent)	440,972	
Petroleum industry (0.4 percent)	6,125	
Glass industry (0.03 percent)	459	
Electrical industry (56.77 percent)	869,236	
Dental and medical industry (8.1 percent)	124,023	
Jewelry and decorative industry (2.5 percent)	38,279	
Miscellaneous (3.4 percent)	52,059	

Source: Minerals Yearbook 1971, Universal Facts and Problems 1970 and Southwest Research Institute.

The determination of consumption figures for individual countries is difficult for several reasons. The high cost of platinoids has created great demand for secondary sources and recovery. Recovery takes place by processing scrap materials which include discarded jewelry, used electronic components and spark plugs, sludges and sweeps. In addition, large quantities of worn out or contaminated platinum-metal-bearing materials are refined on toll. This metal, compromising the bulk of domestic refining operations, was received for reworking or re-refining of depleted catalysts, wornout extension dies, spinners, laboratory ware and other used equipment. Recovery from scrap is very efficient, and only a small quantity of these metals is wasted or lost. Secondary recovery of platinum and palladium in the United States is shown in Table A-10.

While quantities of secondary recovery platinoids are well known for the U.S., the same information for other countries could not be obtained. Furthermore, the trade patterns worldwide as well as within the free world vary considerably. Platinoids are shipped in form of ores, concentrates, residues, waste, scrap and sweepings, partly worked rolled and partly worked not rolled.

Table A-10. Platinum and Palladium Secondary Recovery in the United States (troy oz)

Year	Platinum	Palladium
1967	126,377	215,162
1968	115,587	195,620
1969	126,822	227,763
1970	[r]118,298	[r]208,555
1971	103,429	161,099

([r]: revised)

Source: Minerals Yearbook 1971.

For example, during 1971 the U.S. has exported 404,610 troy oz of platinoids in various metal stages to 17 countries. These shipments included 154,775 oz platinum unworked or partly worked not rolled and 15,894 oz platinum unworked or partly worked rolled. During the same year, the U.S. has imported for consumption 1,302,740 oz from 24 countries in various unwrought or semimanufactured conditions. These inputs included 551,127 oz of platinum and 657,983 oz of palladium. These data indicate that no clear picture emerges from these trade patterns to determine actual consumptions in foreign countries. In addition, and as noted earlier, the U.S.S.R. and the Republic of South Africa, the major platinoid producers in the world, do not publish data on platinoids, and all their figures, found in publications, are estimates by the trade. International trade data for platinoids are available for the year 1969. Some of these data are given for platinum and palladium, some are given as a combination of platinoid and silver shipments and some are given only for non-ferrous metals. In Table A-11, the 1969 percentages of individual countries to the total 1969 world production of platinum and palladium are applied to the 1971 consumption year.

Table A-11. Platinum and Palladium Consumption by Major Country (Order of Magnitude in troy oz)

Country	1971
Canada	68,259
France	312,947
Germany, West	451,330
Italy	74,227
Japan	758,309
Netherlands	32,824
Sweden	17,158
Switzerland	11,563
U.K.	48,863
U.S.S.R.	589,340
U.S.	1,375,788
Total Approximately	3,740,608

Source: Minerals Yearbooks.

The total consumption (3.74 million troy ounces) compares favorably with the 1971 production figure of 3.75 million ounces. The data shown represent an order of magnitude approximation for major consuming countries. With the exception of Japan and the U.S., variations are expected. The causes for these are based on inadequate data on foreign stockpiles, dealer stocks, and foreign secondary recovery. These data also include small shipments of platinoids from major consumer countries to a large number of less industrialized and small countries, caused very likely by Futures trading and speculation.

8. End Use Applications

Platinoids find many applications in industry because of their catalytic activity, resistance to corrosion, resistance to oxidation at elevated temperatures, high melting point, high strength and good ductility. Platinum and palladium are the major platinum metals; iridium, osmium, ruthenium and rhodium are used mainly as alloying elements to modify properties of platinum and palladium. Rhodium is also used in plating.

Chemical industry. One of the major uses for platinum, alloyed with 10 percent rhodium, is as a catalyst in producing nitric acid for use in nitrate fertilizers and explosives. New uses for platinum and palladium as an oxidation catalyst are evolving in the rapidly expanding pollution control field. Platinum and palladium are widely used as a catalyst in hydrogenation, dehalogenation and other reactions used by chemical, dyestuff and pharmaceutical industries.

Platinum and other platinum-group metals are used also as catalysts in a great variety of other chemical processes as shown in Table A-12.

Table A-12. Chemical Processes Using Platinum-Group Metal Catalysts

Process	Catalyst
Hydrogenation	Pt, Pd, Ir, Rh, Ru, Os.
Dehydrogenation	Pt, Pd, Ir, Ru, Pd-Ag.
Fragmentation	Pt, Pd.
Decomposition	Ir, Ru.
Hydrocracking	Pt, Ir.
Reforming	Pt, Ir, Rh, Pt-Ir.
Synthesis	Ir, Rh, Ru.
Polymerization	Ir-Ni, $RhCl_3$.
Isomerization	Pd, $IrCl_3$, Ir-Ni, Ir-V, $RhCl_3$, Pt-Ir, Pt-Rh, Pt-Ru, Pt-Os.
Oxidation	Pt, Rh, Ru, Pt-Ir, Pt-Rh.
Regenerable reagents	$PdCl_3$.
Homogeneous reactions	
Carbonylation	Ir, Ru, $PdCl_3$, $RhCl_3$, $Rh(NO_3)_3$.
Oxidation	Ir, Ru, $PdCl_3$.
Reductions	Ru, Pt-Ir, $RhCl_3$.

Source: Minerals Yearbook 1971

Platinum spinnerets are used in the production of synthetic fibers. New precious-metal catalyst systems are being developed constantly to reduce utilization of platinum at no loss in catalyst efficiency. A precious-metal-plated titanium anode may replace graphite anodes in the chlorine manufacturing industry.

Petroleum industry. Generally, platinum and palladium are used as catalysts in the production of high-octane gasolines and for hydrocarbon synthesis to produce numerous petrochemicals. Reforming units to produce nonleaded gasoline will lead to a substantial increase in platinum consumption. However, application of a new platinum-rhenium catalyst to refining, requiring much less platinum, may offset the demand for this purpose.

Glass industry. A substantial quantity of platinum-rhodium alloy is used for bushings for attenuating the glass fibers and for equipment used in manufacturing other glass products. Glass-making refractory equipment is coated with a thin layer of platinum sheet to prevent contamination of the molten glass. More uses for platinum-iridium alloys are found in crucibles for growing crystals for lasers, optical modulators and other scientific applications.

Electrical and electronic industry. Platinum, palladium and various alloys find major use in such application as light duty contacts, electric furnace windings, thermocouples, cobalt-platinum permanent magnets for travelling wave tubes, resistance thermometers and precision thermometers, relays, meters, voltage regulators, and other electrical instruments. Palladium especially is used in low voltage-low energy electrical contacts in telephone equipment. Platinum and palladium are also used in powder (paste) form or as electrodeposits in components of electrical printed circuits. Platinum is also used in fuel cell electrodes, and new developments in this field could lead to a substantial increase in platinum requirements. Significant quantities of platinum were also used in impressed current corrosion protection systems. Some pacemakers to stimulate the heart muscle use platinum or platinum-iridium electrodes.

Dental and medical industry. Additions of platinum and palladium to gold-based alloys increase strength, hardness and wear resistance, raise the melting temperature and enhance the age hardening of the alloys. These alloys are used extensively in fabricating mechanical aids and devices for application in prosthodontics and orthodontics. Palladium-rich alloys are used as supports in the porcelain-overlay type of dental restoration because palladium does not stain or discolor the porcelain after it is fired. Testing of platinum compounds for their therapeutic value in cancer treatment of humans is well along in many institutes in the U. S. and abroad. The possibility is indicated that platinum compounds knock out or cause remissions in a very broad range of cancers, with little or no side effects. It also appears that platinum may have possibilities as an antiviral agent, and that it may inhibit leukemia.

Jewelry and decorative industry. Platinum, palladium and rhodium are used to fabricate various jewelry articles such as watch cases, rings, broches and other settings. These metals provide lightweight, white, tarnish-free alloys. Palladium-ruthenium alloys are used for large jewelry articles because of their density and thus their light weight. Platinum settings do not mask the true color of diamonds, whereas gold lends a yellow tint. In addition, and because of platinum's mechanical properties, platinum settings hold gemstones more securely than gold.

Miscellaneous uses. These uses of platinum-group metals include laboratory ware such as electrodes and crucibles. Platinum is used to control galvanic corrosion such as the cathodic protection of ship hulls, and as inert anodes in electrodeposition. New uses for control of corrosion are found in the metal, chemical, petroleum, sewage disposal and water supply industries. Brazing alloys which contain palladium have good wetting ability and are relatively free from erosion at high temperatures. These alloys are frequently used in gas turbines, jet engines, and air frames when a high level of reliability is required. Platinum and chromium are used to give razor blades a hard, corrosion-resistant edge. The automotive industry has all but accepted the platinum/palladium/ruthenium based catalytic mufflers for pollution control beginning with 1975 model automobiles. In this system, exhaust gases pass over a platinum catalyst in the muffler and the carbon monoxide (CO) and hydrocarbons (HC) are converted to carbon dioxide and water. Oxides of nitrogen (NO_x), which also have ceilings under Environmental Protection Agency (EPA) guidelines, are not reduced by the platinum catalyst, but can be reduced by lower engine temperatures, engine modifications, or other catalysts in the system. The system must use nonleaded gasoline, because lead, even in small amounts, makes the catalyst inoperable.

Research and Alternates. Extensive research and development programs are pursued with particular emphasis on applications of platinum-group metals in such industries as petroleum and petrochemicals, pharmaceuticals, electrical energy and electrical and electronic products, and powder metallurgy. Considerable effort is being directed toward the development of high-activity platinum electro-catalysts for the direct conversion of chemical energy into electrical energy in fuel cells, and there is an increased interest in research to develop a technically and economically feasible method of recovering palladium and rhodium from atomic wastes.

However, there is also constant economic pressure to substitute less expensive materials for the platinum-group metals in industrial applications. The platinum metals are only used where they are justified technically and economically. Platinum and palladium as well as the minor platinum-group metals are used interchangeably to some extent for certain uses. In some uses, tungsten and nickel alloys, vanadium, silver and gold can be substituted for platinum-group metals. Cladding with platinum-group metals enables the surface properties of the noble metals to be combined with the mechanical strength of cheaper metals. Cladding is common in glass melting pots and in chemical ware. Rhenium-platinum reforming catalysts may replace platinum to some extent in petroleum refining. Cobalt-copper-rare-earth alloys may be substituted for platinum-cobalt as a high-energy magnetic alloy in certain electronic applications.

In the automotive industry, there are three approaches competing with the platinum/palladium catalytic muffler. (1) The nonplatinum catalyst system uses a cheaper catalyst that is resistant to lead poisoning and hence can use currently available gasoline. Some catalysts for this type of system are oxides of vanadium, chromium, manganese, iron, cobalt, nickel, copper, molybdenum, tungsten and rare-earth elements. Although few details have been released on the performance of these systems, they apparently have not been tested as extensively as the platinum system, and their long-term reliability is uncertain. (2) The thermal reactor represents an afterburner to convert CO and HC to carbon dioxide and water, in coordination with engine modifications and exhaust gas recirculation to reduce NO_x. While these systems approach the emission standards for the life

of the car (versus platinum systems 25,000 to 50,000 mile reliability), they reportedly reduce gas mileage and "driveability" considerably. Nevertheless, this system is a strong contender.
(3) Experimental automobiles with radical engine designs are being tested. Their engines are inherently pollution-free. Some of these are steam-driven cars, battery-run electric cars, turbine-engine cars, or they may use the Warren engine and other stratified-charge engines. Although the design changes and lack of proved reliability and other characteristics make these cars unlikely candidates for 1975 production by major manufacturers, some of these engines may be adopted as long-range solutions to the pollution problems in the 1980's.

9. Attrition and Transfer to the Environment

In providing attrition and transfer rates, it is necessary to review the following breakdowns according to published statistics.

Chemical Industry. In 1971, this industry purchased 135,112 oz of platinum and 218,651 oz of palladium. It is estimated that these purchases were divided as follows:

	1971 Platinum (troy oz)	1972 Palladium (troy oz)
Chemical (inorganic)	83,229 (61.6%)	47,227 (21.6%)
Chemical (organic)	51,883 (38.4%)	171,424 (78.4%)
Total Chemical Industry	135,112 (100.0%)	218,651 (100.0%)

The rough data estimates for consumption rates in the chemical industry provided by the Bureau of Mines are for nitric acid production only. These consumption data are related to the latest industry purchased data of platinum and palladium, published for 1971 (Tables A-6 and A-7). In inorganics, the two largest production items using catalysts with platinum-group metals are shown below in billions of pounds (bp):

Sulfuric acid, 100%	58.84 bp
Nitric acid, 100%	13.48 bp.

In organics, the three major production groups, utilizing such catalysts are:

Ethylene	18.30 bp
Cyclohexane	1.75 bp
Benzene	1.08 bp.

The total chemical industry produced in 1971 about 203.00 bp inorganics and about 77.00 bp organics, or a total of 280.00 bp.

Petroleum Refining. The major data in this industry are published for crude-oil throughput capacity, catalytic cracking, catalytic reforming and hydroprocessing. The rough data estimates of consumption rates, available at this time, are for catalytic reforming. The development of total U.S. refinery, cracking and reforming capacities are shown below in 1,000 barrel per calendar day:

Year	Crude Oil Capacity (1000 b/cd)	Cracking Capacity (1000 b/cd)	Reforming Capacity (1000 b/cd)
December 31, 1971	13,284.9	4,512.5	2,885.2
December 31, 1972	13,087.0	4,852.0	3,169.1
December 31, 1973	13,383.0	4,512.5	3,278.1

The following Tables A-13 and A-14 provide rough consumption estimates, available at this time, for use, replacement, scrap, attrition and transfer rates for platinum/palladium catalysts in major industrial use categories. Based on the data shown above, order of magnitude comparisons are possible for amounts of platinum and palladium used in those consuming industries for which detail data are not available at this time.

Table A-13. Estimated Platinum Consumption Rates in the United States (troy oz/Year)

Industry	Replacement Rate	Use Rate	Scrap Rate	Attrition Rate	Transfer Rate to Environment	1971 Purchase for Consumption
Chemical[1] (inorganic)	397,000	---	---	53,000[2]	49,000 est.	83,229 est.
Chemical (organic)	---	---	---	---	---	51,883 est.
Chemical Total	---	---	---	---	---	135,112
Petroleum (reforming)	270,000			over 8,500[3]	over 8,500 est.	---
Petroleum total	---	---	---	---	---	251,876
Glass[4]	---	---	---	---	---	40,703
Electrical	---	92,000	18,000	74,000	74,000 est.[5]	51,940
Dental & medical	---	30,000	900	29,100	29,100 est.	23,097
Jewelry & decoration	---	20,000	4,600	15,400	15,400 est.	18,577
Miscellaneous	---	50,000[6]	---	---	---	19,859
Total known at this time	667,000	192,000	23,500	180,000	176,000 est.	541,164

1) nitric acid production only
2) includes 4000 oz. refining, rest transferred to environment or into products
3) includes losses in reprocessing, does not include entrainment in products
4) no data available
5) includes transfer to environment direct and through manufactured goods
6) scrap, attrition and transfer rates unknown at this time

Source: Bureau of Mines and Southwest Research Institute

Table A-14. Estimated Palladium Consumption Rates in the United States (troy oz/Year)

Industry	Replacement Rate	Use Rate	Scrap Rate	Attrition Rate	Transfer Rate to Environment	1971 Purchase for Consumption
Chemical[1] (inorganic)	---	---	---	---	---	47,227 est.
Chemical[1] (organic)	---	---	---	---	---	171,424 est.
Chemical Total[1]	---	---	---	---	---	218,651
Petroleum[1] (reforming)	---	---	---	---	---	---
Petroleum Total[1]	---	---	---	---	---	2,916
Glass[2]	---	---	---	---	---	237
Electrical[3]	---	425,000	---	---	---	431,505
Dental & medical	---	94,000	3,000	91,000	91,000 est.	61,594
Jewelry & decorative	---	19,000	4,500	14,500	14,500 est.	18,752
Miscellaneous[4]	---	28,000	---	---	---	26,451
Total known at this time	---	566,000	7,500	105,500	105,500 est.	760,106

1) no data available at this time.
2) no data available yet, as glass industry is difficult to assess
3) telephone industry is dominant user; scrap, attrition and transfer rates unknown.
4) scrap, attrition and transfer rates unknown at this time

Source: Bureau of Mines and Southwest Research Institute

10. Supply and Demand Trends

Apparent Supply. U.S. reserves are almost entirely in copper ores with a very small quantity in placers at Goodnews Bay, Alaska. The copper ores are estimated to average about 1 oz of platinum-group metals per 6000 tons of ore. Production from placer deposits at Goodnews Bay, with significant amounts of iridium, rhodium and ruthenium, has been slowly declining in recent years, and the remaining reserve is believed to be relatively small. The aggregate reserve of byproduct platinum-group metals in gold ores also is relatively small.

The recoverable reserve in the Republic of South Africa is estimated at 200 million ounces, averaging on the basis of past production about 70 percent platinum, 25 percent palladium and 5 percent minor platinoids. Actually, the occurrence of platinum-group metals in significant quantities in the Merensky Reef Horizon of the Bushveld igneous complex indicates that the quantity of platinum-bearing ore may be considerably larger. The reserve of byproduct osmium and iridium in the gold ore of the Republic of South Africa is significant. In Southern Rhodesia, prospecting and exploration of the Great Dyke ultrabasic formation has disclosed the existence of platinum-group metals which may potentially reach 100 million ounces.

Ethiopia has provided small quantities of metals from platinum placer deposits for years. Exploration for additional sources is underway.

In Canada, the platinum-group metal content of the proven nickel-copper ore reserve of the Sudbury Basin and Thompson, Manitoba areas is estimated at 16 million ounces, comprising 7.4 million ounces of platinum, 7.0 million ounces of palladium, and 1.6 million ounces of minor platinoids, chiefly rhodium.

Colombian placer deposits contain substantial reserves of platinum.

U.S.S.R. production of platinum-group metals has been rapidly expanding in recent years, and it is estimated that reserves of platinum-group metals in the U.S.S.R. are at least 200 million ounces.

Finland is providing small amounts of platinum-group metals from copper refining.

Japan provides small amounts of platinoids, mostly platinum and palladium as byproducts of nickel-copper refining.

The Philippines are furnishing mostly platinum and palladium from nickel-cobalt concentrates.

In Western Australia, high platinum values were found on the Northwest Oil and Mineral Co. property.

In New Zealand, high platinum values were found on the Georgia-Kaolin Co. property near Kerikeri, North Auckland.

In Papua New Guinea, an independent nation since December 1973, and formerly under Australian administration, increasing platinoid production is expected at or near the island of Bougainville as substantial copper ore deposits are opened up.

Estimated proved reserves of platinum and palladium metals from known conventional sources are shown in Table A-15.

The estimated proportions of six coproduct metals in the platinum group are shown on Table A-16.

Demand. Of immediate effect on the demand for platinum, palladium and possibly ruthenium metals is the development in the automobile emission control and petroleum refining areas. But, the market outlook and hence the market price for these metals is still clouded. In the U.S., the major automobile manufacturers have negotiated substantial supply contracts to permit all-out production of 1975 cars equipped with platinum/palladium based converters. Volvo (Sweden) has contracted for 100,000 antipollution units to equip cars for U.S. delivery. Nissan Motors (Japan) have signed a letter of intent to purchase 400,000 converter devices to equip that firm's cars for U.S. delivery.

Table A-15. Estimated World Reserves of Platinum and Palladium
(million troy oz)

Country	Platinum	Palladium
United States	0.95	1.96
Canada	6.94	6.86
Colombia	5.00	---
South Africa, Republic of	142.40	50.20
U.S.S.R.	60.00	120.00
Total	215.29	179.02

Source: Mineral Facts and Problems, 1970

Table A-16. Estimated Composition of Platinoids by Source
(percent)

Metal	Source Canada	Country U.S.S.R.	South Africa
Platinum	43.4	30.0	71.20
Palladium	42.9	60.0	25.10
Iridium	2.2	2.0	.78
Rhodium	3.0	2.0	2.41
Ruthenium	8.5	6.0	.50
Osmium	---	---	.01

Source: Mineral Facts and Problems, 1970

Toyota Motor Co. (Japan) has also contracted for catalysts, Leyland Motor Corp. (Great Britain) is reportedly negotiating with prospective suppliers of platinum-based converters. Engelhard Kali-Chemie Autocat G.M.B.H. (West Germany) will provide catalysts for Driouer-Benz, Peugeot and Renault cars. Although the Environmental Protection Agency (EPA) has resisted requests for an extension of the 1975 deadline, Detroit is still pressing for delay. This delay is also supported by the Administration for reasons of the current energy and gasoline crises. Despite the fact that the major U.S. manufacturers have negotiated substantial supply contracts, the industry's actual commitment is small, because of the escape clauses in these arrangements.

Perhaps a still more serious problem concerns the availability of unleaded gasoline. Since platinum/palladium catalysts are rendered ineffective by the presence of lead, unleaded fuel must be made available in time to supply 1975 cars, and autofirms have indicated that the maximum residual lead content permissible in such fuels is 0.03 g per gal. However, sources in the petroleum industry have continued to express doubt as to the possibility of producing sufficient quantities of unleaded gasoline in time to meet 1975 auto requirements. It seems almost certain that great quantities of platinum and palladium (and possibly some ruthenium) will be required in manufacturing converters for 1975 automobiles and that the petroleum companies will utilize additional quantities of platinum catalysts in petroleum refining, to boost the octane rating of gasoline without lead additives. It has been estimated by Engelhard that each car will require an average of 0.1 oz of metals including 30-35% palladium and 65-70% platinum. If upwards of 10 million 1975 model U.S. cars were equipped with these converters, then first year requirements beginning in 1974 could amount to 700,000 to 800,000 oz of platinum and 300,000 to 400,000 oz of palladium with still larger quantities demanded in ensuing years.

Based on these factors and allowing for expanded use by auto manufacturers outside the U.S., it has been estimated that world consumption of platinum could increase from an estimated 1.92 million oz in 1972 (Table A-1) to about 3.0 million oz in 1974 and considerably more thereafter. Over the same period, global use of palladium might expand from around 1.98 million oz in 1972 (Table A-1) to perhaps 2.4 million oz in 1974 and 2.6 million oz in subsequent years. These data suggest a possible increment in annual world use during 1972-74 of over 1 million oz of platinum and 500,000 oz of palladium. Present trends of platinum and palladium production were shown in Tables A-1, A-3, and A-4 and estimated reserves in Table A-15.

Among the established producing areas, South Africa may experience the most active growth. As shown in Table A-2, platinum output in 1972 was estimated to be 1 million oz, and palladium output 355,000 oz. The output could be boosted to about 2.5 million oz of platinum and 890,000 oz of palladium in 1975. The U.S.S.R. was expected to produce close to 700,000 oz of platinum and about 1.4 million oz of palladium in 1972. Although she is exporting a substantial amount of both metals, her output in these metals appears to increase. It is estimated that Canada produced about 399,000 oz of platinum group metals in 1972, and that she could increase production to over 500,000 oz.

In emergencies, and if Congress approves the release of stockpile material, platinum and palladium reserves could be provided for eventual sale. The U.S. national stockpile on Dec. 31, 1971 consisted of 402,646 oz of platinum and 507,314 oz of palladium. The supplemental stockpile included 49,999 oz of platinum and 747,680 oz of palladium.

Recent Developments. Supply and demand trends will be influenced, above all, by possible changes in the Clean Air Act with regard to auto emission standards and timing for conformance. Earlier, in April 1973, the EPA had established modified interim standards for auto emissions and granted automobile manufacturers a one-year extension in implementing the federal 1975 exhaust emission standards on all cars manufactured with the exception of those sold in California. Later, at the end of 1973, the Administration requested Congress to amend the Clean Air Act and proposed that 1975 interim levels should be frozen for 2 years to "permit auto manufacturers to concentrate greater attention on improving fuel economy while retaining a fixed target for lower emissions."

On March 22, 1974, the Administration has made several proposals to Congress to sacrifice some air quality for making the nation self-sufficient in energy by 1980. Again included are proposals to freeze the auto-emission standards through 1977.

According to current trade sources, General Motors has indicated it may install platinum/palladium catalytic converters on many of its 1975 U.S. models to ensure compliance with interim standards, and Ford considers that about 25 percent of its 1975 production will be fitted with platinum converters. Other manufacturers expect to use catalytic converters on cars manufactured for the California market. Hence, the EPA extension will have a moderate effect on delaying the projected platinum and palladium consumption in catalytic converters and while the near term requirements have become less stringent, the medium term outlook for these metals appears encouraging.

It also is of interest to note that in July 1973, the Canadian Government announced new exhaust emission control standards for 1975 model cars in Canada that are much less stringent than those adopted by the United States.

11. Medical and Toxicological Information

The information in this section is in part based on two literature searches, conducted by the MEDLINE Data System of the University of Texas Health Science Center at San Antonio and by the National Technical Information Service, U.S. Department of Commerce, Springfield, Va.

Human Exposure Cases

Synopsis. Contact with the platinum oxide has been reported to cause eczematous lesions, and the development of sensitivity to platinum chloride was observed in a chemist, who suffered a generalized eruption from contact with a small amount of the substance. The trioxide has also given rise to dermatitis in the Jewelry and Allied Industries. Photographers have been reported to contract dermatoses from platinum solutions used in their work. Asthmatic symptoms are not uncommon among workers exposed to the salts of platinum. Palladium compounds show little or no irritation, when applied locally to the skin.

Platinum (Pt) is a silver-white metal, tenacious, very malleable, ductile and softer than silver. Exposure to platinum in industry occurs in the metallurgical and chemical processes used in the preparation of the metal and its salts.

Platinum was considered relatively harmless until 1945 when Hunter, Milton & Perry published the results of their investigation of four platinum refineries. They found that, of 91 workers exposed to the dust or spray of complex salts of platinum, 52 suffered from running of the nose, sneezing, tightness of the chest, shortness of breath, cyanosis, wheezing, and cough. Thirteen of the men complained of dermatitis. None of these symptoms were apparent in the workers exposed to metallic platinum dust only, or to the complex salts of the other precious metals, including palladium. The platinum content of the air samples taken at various stations throughout the works was determined spectrographically and found to vary from 5 μg to 70 μg per cubic meter (Fothergill, Withers & Clements, 1945). One may safely conclude, therefore, that the soluble platinum salts, whether carried as dust or mist, present an industrial hazard, and that they should be carefully controlled and not exceed a maximum allowable concentration of 2 μg per cubic meter.

The following case histories are given as examples of the syndrome.

Milne (1970) reports the following clinical record from Australia: The patient, a tall, brown-haired, blue-eyed male, aged 37 years, was first examined in early May 1969, when he stated that he had been born in Germany and had migrated to Australia at the age of 20 years. He had worked as a laborer, a hospital orderly and a laboratory assistant. In 1967, he came to his present position as a chemical assistant in a firm which intermittently processes platinum. He said that he had had no skin affliction of any sort until two years before coming for examination, when his hands broke out in a "weeping rash". He was not directly involved in the handling of platinum alloys or salts at that time but in the course of his daily tasks would often enter the refinery. He went to many practitioners, registered and otherwise, in an effort to obtain a cure. The condition which was mostly diagnosed as "nerves" or "eczema" had slowly regressed until it had become a dry, itchy rash on each hand and wrist. He had, for years, also suffered from occasional acute attacks of asthma, and had consulted many doctors for this.

About a year before being interviewed, he had first worked on platinum refining, without incident. About nine months later he noticed one day that his face was red and itchy. Next day it began to "weep" and took several days to heal. A few weeks later, the same sequence of events occurred, and a fellow workman suggested to him that exposure to platinum salts might be a causative factor.

Although he handled platinum alloys constantly in the interim, the patient then avoided platinum refining for six weeks until the day of interview, when, after only 10 minutes' exposure in the refinery, he noticed facial itch and swelling around the eyes. He stopped work after about half an hour, but "little blisters" formed on his forehead, and they began to "weep". He put hot towels and "Vaseline" on his face in an effort to gain relief, and after an hour he left work feeling "shaky". Soon after his arrival home he vomited, then went to bed, and having drunk a glass of beer, he slept fitfully.

Six hours later, when I saw him, the swelling had largely subsided, but he had noticeable infraorbital oedema and some blotchiness of the face. The itch had almost disappeared. He had no further shakiness, and his hands were unaffected.

In late October 1969, he was interviewed again, and said that he had worked in a different department in the meantime, almost completely detached from precious metals. His general health had improved. The hands and wrists had completely cleared, his face showed no swelling, and the asthma had been "mild"--that is, one attack in four months. There were no patches of eczema anywhere on his body.

For two months after that he was free of skin troubles and in good health, and then, about the beginning of December 1969, he went as usual into the refinery, which he was in the habit of entering once a week to make a complex gold salt--potassium-gold-cyanide. Unknown to him on this occasion, the refining and filtration of platinum salts were in progress. Soon after this, his face broke out again, with "little pimples" over the forehead and cheeks. The skin was itchy, red and swollen. The "pimples" dried up over the next three or four days. His neck was also affected, and the same thing occurred at his wrists. At the time of the interview, a few small, dry patches remained on his wrists.

Since that time he has continued to work away from the precious metal refinery, and has been untroubled by skin complaints except on one occasion, when, according to the firm's chief chemist, he was again exposed, unknown to himself, and a similar series of events occurred.

Parrot (1969) reports the following cases from France:

Case 1. --A 50-yr old man was assigned directly to the platinum refining workshop in January 1960. No personal nor hereditary history of allergy was present. After two months, an erythemato-vesicular, pruriginous dermatitis of the eczema type appeared on the anterior face or wrists and forearms, in the interdigital spaces, and on the elbow folds. An eczematous area was noted on the right thigh behind the pocket where the handkerchief was kept. For three months, this dermatitis was the sole symptom. Then suddenly, at the end of June 1960, an asthmatic condition developed requiring emergency hospitalization. The status asthmaticus persisted for 36 hours, then receded under the action of intravenously administered adrenocorticotropic hormone.

Back to work, he had asthmatic attacks treated with aminophylline (theophylline ethylenediamine). He required another month of hospitalization for asthma. The dermatosis finally vanished.

This worker was then transferred to another department. But if he only entered the platinum-refining workshop or was in presence of platinum workers, that was enough to trigger an attack of dyspnea. Subsequently, from June 1961 to May 1962 hyposensitization to house dusts was carried out because tests for house dusts had been positive, no test with chloroplatinic acid or chloroplatinate had been done. In July 1964, an attack of asthma required emergency transfer to a hospital. Later, although this man had been discharged from the platinum workshop, he continued to have asthmatic attacks when he met people from that workshop.

Case 2. --A 45-year old man was taken on in July 1964 for the manufacture of chloroplatinates. He had no personal nor family history of allergy. After eight months' latency, bouts of nocturnal asthma occurred. These were treated with triamcinolonediacetate and aminophylline. Over one month, the asthma gradually worsened. Attacks occurred during work, more specially during the hydrolysis operations. Then the subject exhibited dyspnea night and day. Despite symptomatic treatment, the dyspnea increased with more or less violent paroxysms. A one-month work stoppage brought complete recovery. Forty-eight hours after return to work this man had a very severe attack of asthma, was transferred to another workshop, and has remained asymptomatic since then. Cutaneous tests were negative but no test with chloroplatinate or chloroplatinic acid was carried out.

Case 3. --A 52-year-old man was employed in 1958 to manufacture chloroplatinic acid. For one year there was no trouble. Then cutaneous pruriginous eczematoid lesions appeared on the forearms, elbow folds, face, and neck. Hydrocortisone acetate ointment produced regression of the dermatitis over the weekend, relapse occurred on Monday when work was resumed. Platinum salts tests were highly positive. Hyposensitization to chloroplatinates and chloroplatinic acid was performed without appreciable result: epidermal reaction with 1/1,000 platinum chloride solution still yielded eczema. This man could carry on with the same work until 1962 when he was transferred to another workshop where palladium was extracted from solutions containing various precious metals among them platinum. Under those conditions slight eczema persisted. In 1964, the factory was moved to a new very modern building. The worker was assigned to chloroplatinate calcination. A generalized eczema immediately occurred, with nightly attacks of asthma. The asthma persisted and attacks occurred several times a day, a violent attack required hospitalization.

This worker resumed his work in May in another workshop where he no longer had contact with platinum salts. Eczema remained cured, but slight asthma persisted, triggered by irritating vapors or by the presence of workers from the platinum refining shop.

Case 4. --A 22-year-old man was assigned to the platinum workshop. Two months later, pruriginous erythema appeared on the forearms, elbow folds, armpits, and interdigital spaces. Dermatitis improved on Saturdays and Sundays but recurred Mondays. For the two subsequent months, lesions reached the neck, groin, and chest. The alternate application of hydrocortisone ointment and acid paste, as well as intramuscularly injected cortisone acetate, brought a complete cure although the patient did not interrupt his work. After eight days, dermatitis recurred. Then, subsequent to slight choking following the accidental inhaling of a few puffs of chlorine, dry cough and then attacks of asthma started. At the hospital, cutaneous tests with chloroplatinic acid and ammonium and sodium chloroplatinate were highly positive: chloroplatinic acid tests in 1/1,000 dilution were followed by an epidermal reaction, then a tremendous cutaneous reaction, so we had to remove the patch right away. Solutions of more dilute chloroplatinic acid and chloroplatinates were also positive. Hyposensitization was not done. Permanent dyspnea developed, exaggerated by activity. This required many days away from work. Transfer to another job brought a complete cure.

Case 5. --A 19-year-old man was employed on March 16, 1964, at platinum refining. After six months on this job, some attacks of asthma occurred at night. They did not occur at work, but dyspnea was permanent and breathing remained wheezy. Weekly work stops for two days would cause complete recession of respiratory signs. Sometimes before the onset of asthma this worker exhibited eczematoid dermatitis on wrists, forearms, face, and neck. He was treated with topical applications of corticoids and aminophylline suppositories. Despite epidermal reaction tests showing allergy to chloroplatinates, chloroplatinic acid, and rubber, no hyposensitization was started. During military service this man was hospitalized, then discharged for asthma and allergic eczema. When back at work, he was assigned to another workshop; asthma did not recur, but eczema persisted. Finally, this man had to leave the factory.

Case 6. --A 23-year-old man was employed at the test laboratory where chloroplatinates were calcined. After seven years, he found that skin contact with such products triggered a nettle-rash reaction after one minute latency which lasted about two hours. These phenomena became more severe: as soon as he walked into the laboratory, conjuntivitis, allergic rhinitis, asthma, and edema of the eyelids appeared for half an hour. Transfer to another department produced complete cure.

Case 7. --A 27-year-old man was employed at the chloroplatinic acid workshop. Three months after starting this work, he exhibited eczema of wrists and forearms, then of the neck. Fifteen days later, while dermatitis remained, bronchial asthma occurred nightly and did not stop for four or five days. Bouts of asthma also occurred during work. Transfer brought cure after one month. Now this man can even walk into the platinum workshop without trouble.

Case 8. --A 30-year-old employee in the chloroplatinate workshop for five months developed eczema on his upper limbs extending to the shoulders; he did not stop working. Since he did not touch chloroplatinates any longer, he remained cured.

Freedman et. al. (1968) report the following case from Canada: Dr. T. T., a 34-year-old inorganic chemist on the teaching staff of a large university in the Montreal area, consulted one of us (S. O. F.) in April 1967, because of possible allergy to platinum salts. His history was that he had worked with platinum compounds for about 10 years. During the previous 3 years, he noted that whenever he came in close contact with platinum salts he would develop acute rhinitis and asthma. His symptoms became progressively worse, finally reaching a point where he could no longer enter his own laboratory without experiencing severe cough, wheezing, and shortness of breath. On one occasion, a solution of ammonium chloroplatinate was accidentally splashed in his face by a co-worker in the laboratory. Almost immediately, he developed massive angioedema of the face and acute generalized urticaria which required epinephrine and steroids for control.

The patient was admitted to the Montreal General Hospital during an asymptomatic period for detailed investigation. In the allergy history, it was determined that the patient had suffered from mild ragweed hay fever for many years and that his daughter had infantile eczema. Otherwise, he was completely free of atopic symptoms, except when exposed to platinum salts.

Complete physical examination was within normal limits. The resting blood pressure was recorded as 140/80 mm Hg. A chest x-ray was reported as showing no evidence of pulmonary, cardiac, or pleural disease. Respiratory function studies showed normal values for the vital capacity, timed vital capacity, maximum breathing capacity, and maximum midexpiratory-flow rate. The electrocardiogram was within normal limits. Thus, there was no evidence for underlying pulmonary or cardiac disease which may have been aggravated in a nonspecific fashion by inert dust particles.

Routine intradermal allergy tests showed moderate positive reactions to house dust and ragweed. There was no peripheral blood eosinophilia.

Marshall (1952) reports from South Africa: Mr. D. B. S., a European male aged 25, was first seen in July 1951 when he complained of a rash affecting his left thigh, hands and face. He gave no history of any previous skin or allergic disease and there was no family history of allergy.

He had worked as a laboratory assistant for over a year and had been employed intermittently during the previous eight months in the preparation of a platinum catalyst. Part of this process consisted of the deposition of platinum metal on a base; and this was accomplished by evaporating chloroplatinic acid over hot plates in an exhaust-ventilated fume cupboard. The fluid had, however, to be stirred by hand and the operator was bound to inhale a certain small amount of fumes and to have his hands contaminated by the acid.

In March 1951, about four months after he had first begun work on this process, the patient began to experience attacks of 'tightness of the chest' while at work. He felt 'as if no oxygen were reaching the lungs'. At the same time his eyes and nose watered and he soaked his handkerchief many times in a day. The attacks worked up to an evening climax, but had passed off by the next morning. On one occasion he was off work for a week with 'bronchitis' which he considers to have been a major attack.

One day in June 1951 he wiped his work bench clean of chloroplatinic acid (concentration unknown) with his handkerchief. The next morning there was a patch of erythema on his left thigh, corresponding to his trouser pocket where he kept his handkerchief. Two weeks later a rash appeared on the dorsa of both hands; and about ten days later still the face became affected.

When first examined he presented a patch of erythematous, oedematous, scaling and excoriated acute dermatitis, about 10 cm. in diameter, on the upper and anterior aspect of the left thigh. The dorsa of both hands and wrists were similarly affected; and there were similar lesions of both cheeks, and oedema of the eyelids.

Patch tests of the substances used in his work were applied to the anterior surfaces of the forearms and the following results were obtained:

1% Hydrochloric acid: Negative after 48 hours.
1% Nitric acid: Negative after 48 hours.
1% Chloroplatinic acid: Positive 4-plus (bullous reaction) in less than 24 hours.

Removed from work and treated only with bland applications, the patient rapidly recovered from his dermatitis and had no further asthmatic attacks.

Hunter, et. al. (1945) report the results of an investigation of workers in four platinum refineries in Great Britain:

Case 1.--R.C., aet. 58, research chemist, worked a refinery A from 1907 to 1924 (18 years). From the first year at this work he noticed a tightness of the chest with a wheeze when certain processes in the refinery which caused a spray were in operation. He noticed a tightening also in the muscles of the back and marked sneezing. There was a watering of the eyes and a dislike of light. He would go home and go straight to bed, and would wake up in the morning quite fit, only to repeat the same symptoms the next day. He was forced to leave the refinery in 1924 because the symptoms became so bad he could no longer carry on. Since then he has been perfectly well. On one occasion he returned to the refinery on business and immediately noticed a tightness of his chest, even though the process to which he was sensitive was not going on in the room. However, it was discovered that sodium chloroplatinate had been weighed out in the room about half an hour previously. There was no family history of asthma. He now showed no abnormal physical signs. His blood count was 4,160,000 red cells per c.c., haemoglobin 111 percent. (photoelectric estimation of alkaline haematin 100 percent., equivalent to 13.8 gm. haemoglobin percent.), white cells 12,200, polymorphs 61 percent., small lymphocytes 6 percent, large lymphocytes 27 percent, large hyalines 6 percent. Dr. D. Jennings reported on an X-ray of his chest--old bilateral apical infection with fibrosis and drawing upward of both hila, emphysema of both bases.

Case 2.--A. W., male, aet. 38, started work at the age of 15 in a chocolate manufacturing factory. He worked here for 6 months and then transferred to platinum refinery A. After six years on this work he noticed that when certain processes were in operation his nose started to run and he would start sneezing. This lasted for half an hour. The symptoms gradually got worse and after ten years he began to get tightness of his chest, shortness of breath, wheeze and cough, but he produced no sputum. He never had an attack at home. The attacks gradually got more frequent and more severe, and two months before he was interviewed he was moved to the "other precious metals" department. Since this move he has not had further attacks. He had had no previous illness, and there was no family history of asthma. On examination no abnormal physical signs were found, except that when he painted a 3 percent solution of sodium chloroplatinate on his forearm a large wheal appeared. His blood count showed 5,120,000 red cells, 100 percent. haemoglobin (photo-electric estimation), 11,200 white cells, 50 percent polymorphs, 41 percent, lymphocytes, 3-5 percent eosinophils, 5.5 percent monocytes. X-rays of his chest showed emphysema.

Case 3.--E. V. N., chest, assistant manager of wet process at refinery B, aet. 28, had worked for five years in the laboratory and for 2-1/2 years as assistant manager of the wet process. Immediately he started on the process he became aware that if he entered the room where ammonium chloroplatinate was dried his nose started to run, producing perfectly clear fluid. He would soak three handkerchiefs in an hour. He would develop severe sneezing attacks and some irritation of his eyes. After he had been there three months these symptoms were followed by tightness of the chest which would last for half an hour, and wheezing which lasted 5 hours. He would be awakened in the early hours of the morning with a cough which might last an hour, but the following day he would be quite fit. He had had no previous illness, and there was no family history of asthma. He entered the drying-room on the day he was interviewed and was observed in an attack. He was cyanosed, dyspnoeic and had an audible wheeze. His respiration rate was 34. He had no clubbing of his fingers. His chest moved evenly, was hyper-resonant with normal air entry but many sibilant rhonchi throughout. There were no other abnormal physical signs. His blood count showed 6,350,000 red cells, 130 percent. haemoglobin (photo-electric estimation), 8200 white cells, 60 per cent. polymorphs, 30 per cent. lymphocytes, 5 per cent. eosinophils, 1 per cent. basophils and 4 per cent. monocytes. X-ray of his chest revealed no abnormality. During the attack he was given 10 minims of 1/1000 adrenalin intramuscularly, but it did not produce any relief of the symptoms, though it raised the pulse rate from 80 to 120.

Case 4.--L. J., aet. 36, process hand, worked 7 years at a chemical plant and then for 14 years at platinum refinery B on the wet process and in the 'other precious metals' department. During the past 3 years he had had attacks of running nose, sneezing, shortness of breath, tightness of the chest, wheeze and cough. He was frequently awakened by attacks of coughing at 2 a.m., and had had such an attack every night for the three months previous to his sick-leave which had lasted 3 weeks at the time of interview. He had never had any attacks while away from the works. He was moved to the time office, but still got some attacks, and was therefore transferred to another department where he would not be exposed to the salts of platinum. He had had pleurisy at the age of 8, and had his tonsils removed 1 year previously because of his asthma. There was no family history of asthma. When examined he had not been at the refinery for three weeks, so he appeared a healthy man, and showed no abnormal physical signs. His blood count showed 4,760,000 red cells, 104 per cent. haemoglobin (photo-electric estimation), 7450 white cells, 57 per cent. polymorphs, 1.5 per cent., eosinophils 39.5 percent lymphocytes and 2 percent. monocytes. Dr. M. H. Jupe reported on an X-ray of his chest as follows: "There are a few scattered calcified nodules over the lung fields. The hilar shadows are well seen, but not excessive."

Case 5.--M. D., female, aet. 20, had worked as a press operator before entering platinum refinery C; 3 months before her interview she was observed sieving spongy platinum without exhaust ventilation or mask, and was seen to be without any symptoms. She said that when she handled the dry complex salt her eyes and nose would run, and she sneezed continuously. She experienced some tightness of the chest the same evening, but this never woke her at night. She had never been ill, and had no family history of asthma. On examination she had no abnormal physical signs. Her blood count showed 4,500,000 red cells, 98 per cent. haemoglobin (photo-electric estimation), 12,000 white cells, 58 per cent. polymorphs, 2 per cent. eosinophils, 3.1 per cent. lymphocytes, 6 per cent. monocytes. X-ray of her chest revealed no abnormality.

Case 6.--A. A., chemist, aet. 33, for past 4 years had been in charge of platinum refinery D. For 12 years before that he had been an analytical chemist. He had no symptoms except when he treated the filtrates with granulated zinc, this caused effervescence and droplets containing complex salts to be thrown into the atmosphere. Then his nose ran and he sneezed. This might last for half an hour. He had no tightness of his chest, shortness of breath, cough or wheeze. He had had scarlet fever as a child, but there was no family history of asthma. On examination, apart from a very mild degree of funnel chest, he had no abnormal physical signs. His blood count showed 5,950,000 red cells, 118 per cent. haemoglobin (photo-electric estimation), 7000 white cells, 60 per cent. polymorphs, 36 per cent. lymphocytes. 1 per cent. eosinophils, and 3 per cent. monocytes.

Toxicological Information

Synopsis:

Platinum:

Exposure to complex platinum salts has been shown to cause allergic symptoms of asthma and dermatitis such as wheezing, coughing, running of the nose, tightness in the chest, shortness of breath, cyanosis, and itching of the skin, whereas exposure to dust of pure metallic platinum causes no symptoms. People working with complex platinum salts are often troubled with dermatitis. This does not appear to include the complex salts of other precious metals.

Palladium:

Toxicity is low. This metal, in the form of palladium chloride, has been administered orally in dosage of about 1 grain daily in the treatment of tuberculosis. These amounts resulted in no toxic effects. Applied locally to the skin, palladium chloride shows little or no irritation. In experimental animals, palladium chloride has been given by intravenous injection, producing damage to bone marrow, liver and kidneys when the dosage was of the order of 0.5 to 1.0 mg per kg of body weight.

Levene (1971) provides the following comments on platinum sensitivity: Disease caused by platinum worked into annular or trinket form is not an everyday problem. Dermatitis from metallic platinum has apparently only been recorded in one patient (Sheard, 1955). However, those concerned in the refining or analysis of platinum are required to work with the complex salts of the metal and it is these which give rise to a characteristic syndrome. The complex salts are sodium, potassium or ammonium tetrachloroplatinate or hexachloroplatinate. Apart from being essential intermediate compounds in the refining and assaying of the metal, they are used in the manufacture of platinum sponge, a finely divided form of the metal which is a most valuable industrial catalyst. Individuals may work in an atmosphere containing these salts for periods of months or years without trouble, but sooner or later the majority of workers will develop symptoms referable to the respiratory system and/or the skin.

The respiratory symptoms were clearly described in a classic paper by Hunter, et. al. (1945) and consist of rhinorrhoea, sneezing, cough, tightness in the chest, wheezing, shortness of breath and cyanosis. In short, they resemble a mixture of hay fever and asthma. Symptoms can arise within minutes of exposure. In the patients reported by Hunter, et. al., 52 of 91 employees who worked in platinum refineries in the London area had the asthma/hay fever syndrome to a significant degree. Thirteen of the 91 had a skin eruption of scaly erythematous type but a few had urticarial lesions. Jordi (1951) in Zurich described 3 cases in which asthma followed inhalation of platinum salts and immediate urticaria followed splashing of solutions on the neck and forearms. One case produced a cutaneous weal within 2 min. of painting with a 3% solution of sodium chloroplatinate but the responses were not clear-cut. Roberts (1951) in Malvern, Pennsylvania investigated reactions seen in employees in a platinum laboratory and refinery over a period of 5 years. He coined the term "platinosis" for the syndromes he encountered.

He noted that once disabling symptoms arose in any one case that person never again became asymptomatic in a platinum-containing atmosphere. His observations concurred exactly with the other reports, and it was advised that sufferers from the effects of platinum salts should be transferred to other work. Five cases with both asthma and eczematous dermatitis have been described from Paris by Parrot, et. al. (1969), in a study of 51 subjects 35 had symptoms of platinosis. Freedman and Krupey (1968) report a man with the respiratory syndrome who developed massive angio-oedema and acute generalized urticaria following accidental splashing of ammonium chloroplatinate solution on the face.

Roberts carried out scratch tests with aqueous solutions of sodium chloroplatinate on 60 platinum workers. He found that all subjects developed a one plus (+) reaction with a 1:10 dilution of the salt. Following the onset of symptoms, either of the cutaneous or respiratory type, a reaction was always obtained with a 1:1000 dilution. He decided that initial scratch-testing was an unreliable index of liability to develop future symptoms and he claimed that a person with a strong personal or family history of atopy or of contact dermatitis was more likely to succumb to platinosis than others. However, he believed that individuals with moles, acne or sebaceous cysts were also particularly prone to the condition.

The elicitation of an immediate skin weal and symptoms resembling asthma and hay fever after exposure to complex platinum salts suggest that either a pharmocological or an allergic histamine liberating process is operating. Parrot, et. al. (1963) injected sodium chloroplatinate solution intravenously into normal guinea pigs and found that when a sufficient dose was given, the animal developed intense asthma and died within a few minutes. Smaller doses provoked non-fatal asthma, and if the dose was repeated several times the effect became successively less intense. Complete protection against such asthmatic episodes was afforded by prior injection with the antihistamine drug mepyramine. From these observations and further experiments using isolated guinea pig ileum in vitro, the authors concluded that platinum salts act as powerful histamine liberators in the guinea pig. However, despite these findings it seems clear that the clinical syndrome of platinosis in man is largely the result of hypersensitivity to platinum salts. Evidence in favour of this contention is as follows: (1) workers do not have symptoms initially, the syndrome comes only after months or even years of exposure to the salts, (2) symptoms increase in severity with repeated exposure, (3) cutaneous scratch tests to platinum salts at a dilution of 1 1000 become positive with the onset of symptoms when they had been previously negative (Roberts, 1951), (4) passive transfer tests (Prausnitz-Küstner reaction) using patient's serum have been positive using both the platinum salt alone and in conjunction with human serum albumin (Freedman and Krupey, 1968).

It is worth pointing out that scratch or intradermal testing can be hazardous to the point of being life-threatening in these patients. A single intradermal test using potassium hexachloroplatinate at a concentration of 1 μg/ml produced an anaphylactic reaction in the patient of Freedman and Krupey (1968). It is wise for these patients to be protected by systemic antihistamine prior to skin testing.

It has hitherto been recommended that patients with platinosis should change their occupation. There is no doubt that this management is effective since symptoms resolve rapidly when the patient is removed from exposure to platinum salts. However, since the main components of the syndromes of sensitivity to platinum salts are those of an hypersensitivity response, it would seem reasonable to attempt hyposensitization by progressively increasing intradermally injected doses of platinum salt in a way analogous to that employed using pollen in hay fever (Frankland, 1965), and streptomycin in cases of immediate hypersensitivity to this drug (Cohen, 1954; Levene and Withers, 1969).

Successful hyposensitization was recently achieved in an analytical chemist who exhibited typical severe symptoms of hay fever, asthma and contact urticaria when exposed to platinum complex salts in the course of his work (Levene and Calnan, 1971). Starting with a dose of 10 ng he was given increasing doses of ammonium hexachloroplatinate intradermally several times daily for a month. Immediate symptoms were weal and flare at the site of injection, and wheezing and flushing, which usually passed off within 30 minutes. On the twelfth day of the course of injections he began to develop crops of widespread symmetrical erythematous papules and joint pains coming on 2 hours after injection, i.e. he developed a serum sickness-like reaction. Histology of the papules showed an intense perivascular infiltrate of polymorphonuclear leukocytes--mainly eosinophils. The injection sites at first produced very prominent weals and flares but these tended to diminish with increasing doses. At first the weals faded rapidly with no sequelae but later in the course, with higher doses, the injection sites developed pinkish-brown tender papules after the initial weal had subsided. With the highest injected dose (100 μg), the injection site became very tender and necrotic after 2 days. The appearance resembled the Arthus phenomenon as seen in experimental animals. An injection of this dose into a normal subject produced only a slight transient reaction at 24 hrs. By this time it was found that the patient could carry out his usual work and handle ammonium hexachloroplatinate without the hay fever and asthma symptoms and urticaria which had previously partially disabled him. He remained well while working with hexachloroplatinate although a chance exposure to tetrachloroplatinate produced symptoms, suggesting that his reduced sensitivity was specific for the hexachloroplatinate. A further chapter in his pathology occurred after he stopped working with platinum salts for about 3 months. When he was again exposed he found that he had partially relapsed, and he required readmission to hospital for a further course of injections. Since then, he has had continuous exposure and has remained well.

It is of interest to consider the mechanism of his hypersensitivity and its amelioration by the technique of hyposensitization. It is postulated that the original symptoms were mediated by reaginic (IgE) antibody and that injections of the platinum salt stimulated production of IgG (blocking) antibody which combined preferentially with the antigen to prevent anaphylactic symptoms. The development of a serum sickness-like and Arthus-like reaction during hyposensitization give support to this hypothesis since there is evidence that such reactions are caused by immune complex formation involving precipitating antibody (Cream and Turk, 1971). Although specific IgG antibody was not directly demonstrable in this case by double diffusion in agar or by haemagglutination using either the platinum salt alone or in conjugation with human serum albumin, it was found that intradermal injection of the platinum salt incubated with post-hyposensitization serum gave a much smaller weal and flare than salt incubated with pre-hyposensitization serum. This indicated that post-hyposensitization serum had acquired the ability to block the immediate weal and flare response and it seems very likely that newly formed IgG antibody was responsible for this blocking activity. The platinum salt presumably acts as a hapten which combines with an endogenous protein to form an allergenic hapten-protein complex. A likely candidate for the protein concerned is serum albumin as suggested by Freedman and Krupey (1968). Although it has been assumed that the anaphylactic symptoms in these cases are the result of IgE antibody, it has recently been shown (Parish, 1970) that IgG antibody can have limited anaphylactic activity. However, Parish considers it unlikely that anaphylactic IgG could participate in the classical reagin-mediated reactions--asthma, hay fever, or urticaria--that occur within minutes of exposure to antigen.

The situation with regard to the eczematous dermatitis in response to complex platinum salts as described by several authors is less clear. It is quite likely that allergic contact sensitivity can occur but this has not yet been convincingly proven by patch tests in appropriate cases. Allergic contact sensitivity is a delayed hypersensitivity reaction, and the situation is complicated by the well-documented ability of these salts to produce urticaria on contact. It is not even clear what is an appropriate concentration to be used for patch testing. For a patch test to be valid it must, of course, be shown that the chosen concentration does not produce an irritant reaction in control subjects (Bett and Calnan, 1957). Complex salts of platinum are not readily soluble in distilled water, but solubility is improved if physiological saline is used. They dissolve in dilute hydrochloric acid but such solutions are probably not suitable for patch testing. These problems remain to be resolved.

Although platinosis is a rare disease outside platinum refineries, recent reports indicate that platinum salts may be of value in cancer chemotherapy (Rosenberg, et al., 1969, Harder and Rosenberg, 1970). Platinum compounds have not been widely used as therapeutic agents despite an early report that they were "very effective" in syphilis and rheumatism (Hoefer, 1841). If these compounds do come into general use, one can anticipate that allergic reactions to them may be seen.

Schroeder, et. al., (1971) report on studies of the innate effects of low doses of abnormal trace elements in drinking water on mice and rats exposed for life, conducted in an environment built so as to exclude metallic contaminants:

In order to evaluate possible innate toxic effects of small doses of rhodium and palladium in terms of growth and survival, mice divided as to sex were raised in an environment limited in metallic contamination and given 5 ppm metal in drinking water from weaning until natural death. Body weight was measured at monthly intervals up to 6 months, at 1 year and at 18 months of age. The feeding of palladium was associated with growth suppression at 7 and of rhodium at 6 of 16 intervals compared to mean weights of controls. Survival of palladium-fed males was greater than that of controls. Tumors were found at necropsy in 16.3% of one group of controls, 28.8% of the rhodium and 29.2% of the palladium groups. Malignant tumors were increased in rhodium and palladium groups, at a minimally significant level of confidence ($P < 0.05$), all but one tumor being malignant. In a second series, tumors were present in 26.8% of controls. All tumors in these latter groups were malignant. Rhodium and palladium appear to exhibit slight carcinogenic activity in mice.

Spikes, et. al., (1969) report on experiments of enzyme inhibition by palladium chloride·

In the course of examining palladium porphyrins as possible sensitizers for the photodynamic inactivation of enzymes, it was observed that palladium (+2) inactivated trypsin directly by a non-photochemical process. Although palladium (+2) has been shown to bind to proteins such as carboxypeptidase, casein, papain and silk fibroin, and to interfere with plant growth, reports were not found in the literature on its action as an enzyme inhibitor. For this reason a preliminary examination of the effects of palladium (+2) on several enzymes was carried out.

Of the enzymes listed above, only chymotrypsin and trypsin were inactivated by palladium (+2). The inactivation was time- and pH-dependent. Trypsin was very rapidly inactiviated at pH 4.2, but was not inactivated at pH 8.9. Alphachymotrypsin was also inactivated very rapidly at pH 4.2, but, in contrast to trypsin, was inactivated fairly rapidly at pH 8.9.

The mechanism of the inactivation of chymotrypsin and trypsin by palladium (+2) is not known. Other metals (copper, zinc, mercury) in the divalent form also inhibit these enzymes; mercury presumably inhibits trypsin by reacting with sulfhydryl groups. It has been suggested that mercury may inactivate chymotrypsin (which has no free sulfhydryl groups) by forming a stable chelate with the active-site histidine. Palladium (+2) binds to papain with the same stoichiometry as does mercury (+2), which suggests that, for this enzyme, its binding is due to interaction with sulfhydryl groups. Palladium (+2) forms complexes with L-cysteine, L-cystine and L-methionine in solution, but not with L-histidine. Thus, one could envision that palladium (+2) inactivates trypsin by combining with free sulfhydryl groups and/or with cystine groupings, while the inactivation of chymotrypsin might result from reactions with cystine groupings.

Wood (1974) reported recently:

Platinum and palladium will be methylated in the environment by microorganisms. These metabolic products could be more toxic than other forms of the metals. Platinum and palladium were listed as very toxic and relatively accessible.

Summary of Medical and Toxicological Information

Metallic platinum is non-toxic and never gives rise to occupational injury. The oxide causes eczema of the hands and forearms and some lesions of the nails. Dust and spray from the complex salts of platinum have been found to cause asthma after continued exposure. The initial symptoms of the reaction begin with repeated sneezing followed by a profuse running of the nose with a watery mucous discharge. Later reactions which may develop are tightness of the chest, shortness of the breath, with wheezing and blue coloration of the face. When the operator leaves the work, the symptoms clear with the exception of the persistent bouts of coughing in the night which may endure for about one-half hour. When the work is resumed, the symptoms recur. Certain typical skin reactions may also develop in some individuals; this is characterized by a scaly red rash. Blood checks, skin tests, and X-rays do not reveal any abnormalities leading to the lesions noted. Precautions lie in minimizing the exposure by adequate means not to exceed a maximum allowable concentration of 2 μg per cubic meter for the soluble platinum salts. Treatment consists in removal from exposure and consultation with a physician with a full-history of the exposure.

Palladium salts commonly used are the chloride and the amino-nitrite. So far as is known, the palladium salts do not constitute any threat of injury in industry, but laboratory tests show that when these substances are introduced in animals, damage occurs to the heart, kidneys, liver and bone marrow. From these indications, it would seem that palladium salts should be carefully watched for chronic and cumulative toxic effects.

The Environmental Protection Agency has efforts underway at EPA-Cincinnati on the toxicity of platinum and palladium. The results of these studies should provide substantial additions to the toxicity data presently available.

APPENDIX B. ANALYSIS AND PROJECTIONS

1. End Use and Production Projections

The projected forecast base for total demand of platinum and palladium was established for each of the end use categories. The forecast bases were derived by relating domestic end uses of each metal in 1971 to the anticipated growth of such indicators as the gross national product (GNP) or total population, adapted from the White House Conference on the Industrial World Ahead· A Look at Business in 1990. Relevant contingency factors, which would have a positive or negative influence on the projected demand in each end use category, were then considered to obtain a high and low range of demand. The aggregation of these internal ranges for each end use category constitutes the median, low and high forecast ranges in the years 1980 and 1990 for platinum and palladium.

In the rest of the world, the demand for platinum catalysts in the petroleum industry is increasing more rapidly than in the United States as the use of platinum in reforming processes to produce higher octane motor fuels is being adopted. Rest-of-the-world growth in chemical uses will probably increase fairly rapidly as the demand for fertilizer materials increases. Within the electric industry, where palladium is used, the move to electronic and other means of switching may result in a relatively slow rate of future growth in the rest of the world. Demand in dental, medical, glass and jewelry applications in other countries will probably grow at rates approximating those in the United States. Based upon these considerations, the rest-of-the-world demand for platinum is expected to range between 1.565 and 2.087 million ounces in 1980 (with a median of 1.826 million ounces), and between 2.317 and 3.089 million ounces in 1990 (median, 2.703 million ounces). The growth rate corresponds to 4.0 percent. The rest-of-the-world palladium demand is expected to range between 1.182 and 2.128 million ounces in 1980 (median, 1.655 million ounces). In 1990, the range is projected from about 1.750 to 3.150 million ounces at a median of 2.450 million ounces. The median growth rate corresponds also to 4.0 percent. The following Tables B-1 and B-2 show the domestic and rest-of-the-world forecast ranges of demand for platinum and palladium. Tables B-3 and B-4 present forecast bases for each category of end use.

Table B-1. Forecast Range of World Demand for Platinum
(thousand troy oz)

		1971	1980	1990
	high	---	1900	2442
United States	median	541	1508	1910
	low	---	1141	1453
	high	---	2087	3089
Rest-of-the-world	median	1283	1826	2703
	low	---	1565	2317
Total world demand	high	---	3987	5531
estimate	median	1824	3334	4613
	low	---	2706	3770

Source: Mineral Facts and Problems 1970 and Southwest Research Institute

The projections for platinum and palladium in catalytic mufflers are based on an immediate demand of 700,000 oz platinum and 300,000 oz palladium, required at the original 1975 timetable. The rest-of-the-world demands in 1971 are taken from Tables A-3, A-4, A-8, and A-9, where it was shown that about 1.82 million oz of platinum and about 1.92 million oz of palladium were produced in 1971. The projection of production figures to 1980 and 1990 are given in terms of requirements from major producers on Table B-5.

A comparison of the 1975 production objectives for major producing countries with the projected world demand shows that a constant 1975 production rate for platinum would meed the 1980 median demand, whereas the constant 1975 production rate for palladium would not meet the 1980 median demand. Based on the 1975 objective, it would appear that the world platinum production needs to be increased by 2.064 million oz to meet the 1990 high demand projection, and by 1.146 million oz to meet the 1990 median projections. World palladium production would need to be increased

Table B-2. Forecast Range of World Demand for Palladium
(thousand troy oz)

		1971	1980	1990
United States	high	---	1589	1919
	median	760	1230	1466
	low	---	782	962
Rest-of-the-world	high	---	2128	3150
	median	1163	1655	2450
	low	---	1182	1750
Total world demand estimate	high	---	3717	5069
	median	1923	2885	3916
	low	---	1964	2712

Source Mineral Facts and Problems 1970 and Southwest Research Institute

Table B-3. Contingency Forecasts of U.S. Demand for Platinum by End Use, 1980 and 1990
(thousand troy oz)

End Use by Industry	U.S. Demand 1971	U.S. Forecast Base 1980	U.S. Low 1980	U.S. High 1980	U.S. Forecast Base 1990	U.S. Low 1990	U.S. High 1990
Chemical, (inorganic)	81	117	105	195	177	159	295
Chemical, (organic)	54	60	43	69	67	48	77
Petroleum	252	365	261	489	551	394	738
Glass	41	59	54	88	90	83	135
Electrical and Electronic	52	58	30	74	64	33	82
Dental and Medical	23	25	25	50	28	28	56
Jewelry and Decorative	18	21	19	47	23	21	51
Miscellaneous	20	29	24	36	44	37	55
Automotive Catalysts	---	774	580	852	866	650	953
Total (Rounded)	541	1508	1141	1900	1910	1453	2442

Source: Mineral Facts and Problems 1970 and Southwest Research Institute

by 2.196 million oz to meet the 1990 high demand projection, and by 1.343 million oz to meet the 1990 median projection. Table A-15 showed that platinum reserves of major producing nations are estimated as 215.29 million oz and palladium reserves as 179.02 million oz. It would appear that the projected demands for platinum and palladium can be met amply during the forecast period from known reserves.

2. Contingency Assumptions

Contingency assumptions made to establish the U.S. forecast range of demand for each end use in 1980 and 1990 are presented below.

Industrial Inorganic Chemicals. The forecast base in the years 1980 and 1990 for this end use was obtained by relating the growth in demand for platinum and palladium to the growth in GNP which is anticipated as 4.2% annually according to the White House Conference Board. The forecast bases of demand for platinum are 117,000 (1980), 177,600 (1990) oz and for palladium 191,000 (1980) and 289,000 (1990) oz. The chemical industry is a large consumer, especially for the production of nitric acid which is used in tonnage quantities in the production of fertilizers and explosives. With the steady increase in population as well as demand for food products world wide, there is a continuing demand

Table B-4. Contingency Forecasts of U.S. Demand for Palladium by End Use, 1980 and 1990 (thousand troy oz)

End use by Industry	U.S. Demand 1971	U.S. Forecast Base 1980	U.S. Low 1980	U.S. High 1980	U.S. Forecast Base 1990	U.S. Low 1990	U.S. High 1900
Chemical (inorganic)	132	191	179	298	289	271	452
Chemical (organic)	87	96	96	128	108	108	144
Petroleum	3	4.3	3.2	6.5	7	5.3	10.5
Glass	0.20	0.29	0.27	0.43	0.44	0.40	0.66
Electrical and Electronic	432	478	212	584	534	237	653
Dental and Medical	61	69	69	104	77	77	116
Jewelry and Decorative	19	21	21	49	23	23	54
Miscellaneous	26	28	36	54	57	54	81
Automotive Catalysts	---	332	166	365	371	186	408
Total (Rounded)	760	1230	782	1589	1910	962	1919

Source: Mineral Facts and Problems 1970 and Southwest Research Institute

Table B-5. World Production Requirement for Platinum and Palladium

	World Demand (thousand troy oz)			Production Objective 1975 (thousand troy oz)			
	1971	1980	1990	Canada	U.S.S.R.	U.S.A.	Total
Platinum:							
high	---	3987	5531	---	---	---	---
medium	1824	3334	4613	217	700	2550	3467
low	---	2706	3770	---	---	---	---
Palladium:							
high	---	3717	5069	---	---	---	---
medium	1923	2885	3916	283	1400	890	2573
low	---	1964	2712	---	---	---	---

Source: Southwest Research Institute

for fertilizers. The demand for explosives may increase due to increased activity in mining and quarrying operations and in the construction of roads, dams and reservoirs. The present rate of growth for the chemical industry is about 10 percent per year. At this growth rate, the high demand for platinum would be 195,000 (1980), 295,000 (1990) oz and for palladium 298,000 (1980) and 452,000 (1990) oz. More efficient use of these metals or the use of alternate metals in catalysts for producing nitric acid may contribute to a low demand for platinum and palladium. It is also possible that nitrogen replenishment of the soil by direct application of ammonia will increase substantially. Additionally, the use of mechanized boring machines for mining and quarrying operations may reduce the demand for explosives. These contingencies may result in a low demand for platinum of 105,000 (1980), 159,000 (1990) oz and for palladium of 179,000 (1980) and 271,000 (1990) oz.

Industrial Organic Chemicals. The forecast bases in the years 1980 and 1990 were obtained by relating the growth in demand for platinum and palladium to the anticipated growth rate of total population at 1.125 percent per annum, resulting in platinum demand of 60,000 (1980), 67,000 (1990) oz and in palladium demand of 96,000 (1980) and 108,000 (1990) oz. The use of medicinals proportional to total population will probably rise due to increase in longevity and an expansion in Medicare and other health programs. It is also anticipated that synthetic fibers will be used increasingly in lieu of natural fibers. Thus, the demand could reach highs for platinum of 69,000 (1980), 77,000 (1990) oz and for palladium 128,000 (1980) and 144,000 (1990) oz. A low demand in this category may result from the development of alternative processes for producing medicinals. Moreover, education may result in higher health standards achieved through preventive medicine. New techniques in fabricating and producing synthetic fibers may reduce the demand for spinnerets made from platinum-group metals. Due to these contingencies, the low demand could be for platinum 43,000 (1980), 48,000 (1990) oz and for palladium 96,000 (1980) and 108,000 (1990) oz.

Petroleum Refining. The forecast bases in this end use are for platinum 365,000 (1980), 551,000 (1990) oz and for palladium 4,300 (1980) and 7,000 (1990) oz, obtained by relating the growth in this sector to the projected growth of the GNP at 4.2 percent per annum. Increased affluence could result in greater production of automobiles and other motorized recreation vehicles, and thus in increased demand for gasoline. As lead is outlawed as a means of controlling antiknock characteristics of gasoline and for rendering catalytic mufflers effective, platinum requirements may be substantially increased in the production of gasoline of higher octane ratings. Based on the increased mobility, limitations on environmental pollution, and other considerations, the demand for platinum could reach a high of 489,000 (1980), 738,000 (1990) oz and for palladium 6,500 (1980) and 10,500 (1990) oz. However, innovations in transportation such as the development of electric automobiles or the introduction of mass transit systems would severely limit the demand for gasoline. In addition, new techniques in petroleum refining or use of alternate materials for catalysts could reduce the demand for platinum and palladium. These contingencies could result in a low demand for platinum of 261,000 (1980), 394,000 (1990) oz and for palladium of 3,200 (1980) and 5,300 (1990) oz.

Glass Industry. The end use in this category was obtained by relating the growth to the GNP at 4.2 percent per annum, resulting in forecast bases for platinum of 59,000 (1980), 90,000 (1990) oz and for palladium of 290 (1980) and 440 (1990) oz. Concern over fire hazards could lead to increased use of fire-resistant glass fibers for carpeting and drapes by the domestic and industrial sectors. Also, tire manufacturers may adopt increasingly the use of fiberglass for belting in tires. Moreover, if there is a drastic change in transportation, fiberglass belting may be used for conveyer-type sidewalks. Fiberglass will probably be utilized increasingly in the production of boats, snowmobiles and car bodies. Based on these assumptions, a high demand could result for platinum of 88,000 (1980), 135,000 (1990) oz and for palladium of 430 (1980) and 660 (1990) oz. However, mass transportation systems may greatly reduce the demand for automobiles. Manufacturers may continue to use aluminum in boats. Moreover, natural fibers, chemically treated for fireproofing, may be aesthetically preferred to glass fibers. These considerations could result in a low for platinum of 54,000 (1980), 83,000 (1990) oz and for palladium of 270 (1980) and 400 (1990) oz.

Electrical and Electronic Industry. The forecast bases for platinum of 58,000 (1980), 64,000 (1990) oz and for palladium of 478,000 (1980) and 534,000 (1990) oz were obtained by relating the growth in this end use to the projected growth rate of total population at 1.125 percent annually. Due to affluence and the growth in population, communications equipment, including telephone and television, is expected to be in large demand. It is also likely that fuel cells which will utilize platinum or palladium will be developed. Moreover, the reliability of platinum-group metals as electrical components will sustain their use in aerospace applications. These contingencies could result in a high demand for platinum of 74,000 (1980), 82,000 (1990) oz and for palladium of 584,000 (1980) and 653,000 (1990) oz. Conversely, current applications, utilizing these metals may decline. For instance, the major use of thermocouples, containing platinum, is currently in the steel industry. The production of steel by the basic oxygen furnace requires fewer thermocouples than production by the open hearth and the electric furnace. Demand for spark plugs with platinum contents in aircraft engines is expected to decline due to increased use of jet propulsion. Use of other metals in alloys for magnet materials and increased use of solid state devices for electronic switching will contribute to a decline in demand for platinum-group metals. These contingencies could result in a low demand for platinum of 30,000 (1980), 33,000 (1990) oz and for palladium of 212,000 (1980) and 237,000 (1990) oz.

Dental and Medical Industry. The forecast bases for platinum of 25,000 (1980), 28,000 (1990) oz and for palladium of 69,000 (1980) and 77,000 (1990) oz were obtained by relating the growth in this end use to the anticipated growth rate for total population of 1.125 percent per annum. Affluence, increased awareness of dental hygene and vanity considerations will probably result in increased attention to orthodontic treatment and prosthetic dentistry. Hence, the use of the platinum-group metals in corrective devices for straightening teeth, dental plates, and supports may result in a high demand for platinum of 50,000 (1980), 56,000 (1990) oz and for palladium of 104,000 (1980) and 116,000 (1990) oz. Conversely, prophylaxis either through teaching or through such means as chemical treatment of drinking water with fluoride may decrease the need for dental plates or other prosthetic devices. These considerations could result in a low demand for platinum of 25,000 (1980), 28,000 (1990) oz and for palladium of 69,000 (1980) and 77,000 (1990) oz.

Jewelry and Decorative Industry. The forecast bases for platinum of 21,000 (1980), 23,000 (1990) oz and for palladium of 21,000 (1980) and 23,000 (1990) oz were obtained by relating the growth in this category to projected growth of total population at 1.125 percent annually. On the assumption of increased affluence and the desire for quality jewelry, the demand can be expected to reach a high for platinum of 47,000 (1980), 51,000 (1990) oz and for palladium of 49,000 (1980) and 54,000 (1990) oz. However, changes in style and taste may result in a low demand for platinum of 19,000 (1980), 21,000 (1990) oz and for palladium of 21,000 (1980) and 23,000 (1990) oz.

Miscellaneous Uses. These uses include such applications as laboratory ware and brazing alloys containing the platinum-group metals. The forecast bases for platinum of 29,000 (1980), 44,000 (1990) oz and for palladium of 38,000 (1980) and 51,000 (1990) oz were obtained by relating the growth in this end use to the growth in the GNP of 4.2 percent per annum. The forecast bases for automobile catalysts for platinum of 774,000 (1980), 866,000 (1990) oz and for palladium of 332,000 (1980) and 371,000 (1990) oz were obtained by relating the growth in this end use to the projected growth rate of total population of 1.125 percent per annum. The high demand may be realized by the development of industrial anti-pollution devices and by fuels cells which may use platinum-group metals: platinum 36,000 (1980), 55,000 (1990) oz and palladium 54,000 (1980), and 81,000 (1990) oz. The low demand in miscellaneous uses could be as the result of the substitution of alternate metals. The low demand would be for platinum 24,000 (1980), 37,000 (1990) oz and for palladium 36,000 (1980) and 54,000 (1990) oz.

The low demand for catalytic mufflers in automobiles may be due to alternate catalytic materials or due to different technical solutions to the emission problems. The low demand for platinum would be 580,000 (1980), 650,000 (1990) oz and for palladium 166,000 (1980) and 186,000 (1990) oz respectively. The high demand could be realized, if the alternate materials and technical solution would not be feasible. These considerations could result in a high demand for platinum of 852,000 (1980), 953,000 (1990) oz and for palladium of 365,000 (1980) and 408,000 (1990) oz.

3. U.S. Supply and Demand Statistics

Table B-6 shows salient U.S. platinum and palladium statistics for the latest published year.

Table B-6. Salient Platinum and Palladium Statistics for 1971

	Platinum	Palladium
United States	(18,029)	---
Mine production	---	---
Refinery production	---	---
New Metal	10,198	20,951
Secondary Metal	103,420	161,099
Exports (except manufacturers)	319,642	76,471
Imports for consumption	551,127	657,983
Stocks Dec. 31: refiner, importer, dealer	445,821	316,126
Consumption	541,164	760,106
World Production	1,823,763	1,922,979

Source: Minerals Yearbook 1971 and Southwest Research Institute

Data on mine production include production from crude platinum placers and byproduct platinum-group metals recovered largely from domestic gold and copper ores. The product from placer dredging operations at Goodnews Bay, Alaska assays about 64 to 76 percent platinum and 0.23 to 0.39 percent palladium. Byproduct production from copper and gold refining is mostly palladium.

U.S. exports of platinum-group metals include 79 percent platinum of a total of 404,610 oz for all metals. It was assumed that 18.9 percent represented palladium and 2.1 percent minor platinum-group metals.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT An intensive search of the literature provides the basis for the following conclusions concerning platinum and palladium.

Supply and Demand. An average of 3.7 million troy ounces of platinum and palladium were produced in the world in the four-year 1969-1972 period. The United States consumed about a third of this. The proved world reserves amount to some 394 million troy ounces, with considerable promise of increasing these reserves through new explorations. Half of the proved reserves are in the Republic of South Africa and 45% in the Soviet Union. Projected 1980 and 1990 world demands and 6.2 and 8.5 million troy ounces per year, respectively. The introduction of a new demand for automotive emission control catalyst purposes (18% of the total in 1980 and 15% in 1990) is not expected to upset the world supply/demand situation.

The assumption does not consider the possibility that other countries may adopt the catalytic muffler for their use. If this occurs, there will be a larger demand on platinum and palladium resources. Although it appears that the projected demands on platinum and palladium reserves can be met with known sources, it should be pointed out that the United States is almost completely dependent upon foreign sources. The United States currently consumes nearly 40% of the world production, but it produces less than 1%.

Health Hazards. No data exist by which an estimate can be made of transfer of platinum and palladium to the environment. Investigations show that only the salts of platinum present human health hazards. Industrial exposure to these is limited to the mining and refining of platinum ores and the preparation of catalysts for chemical and petroleum refining industries.

17. KEY WORDS AND DOCUMENT ANALYSIS

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Platinum catalysts Palladium catalysts Catalytic converters - automotive Trace contaminants Heavy metal pollution Auto emissions		

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