A MARKET ANALYSIS OF THE FISSION
PRODUCTS Rh, Pd, Ru AND Tc

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INTRODUCTION

Fission-produced platinum metals are generally considered as harmful radioactive wastes that require storage in a glass-like matrix for centuries. When these same metals (rhodium, palladium, ruthenium and technetium) are considered in the context of an ever-increasing demand for the platinum metals and their finite and diminishing reserves, these fission-produced metals become potential resources.

Since the fission-produced platinum metals have radioactive isotopes, the use of these materials should be based on a clear and unambiguous determination of potential radiological hazard as well as the adequacy of our platinum metal supply (foreign and domestic).

At least three studies of the fission-produced platinum metals have been made. Rohrmann⁽¹⁾ considered the use of fission product rhodium and palladium without detailed consideration of the radiological hazards associated with their use. Newman and Smith⁽²⁾ concluded that the recovery of fission-produced platinum metals is not imperative because of adequate mineral reserves and indicated that the contamination of natural platinum metals with radioactive rhodium, palladium, and ruthenium would introduce irreversible hazards. Roberts⁽³⁾ has considered the radiological effects of using fission product Rh, Ru, Pd and Tc and has concluded that such metals could be used if economic and technological incentives dictated. The purpose of this report is to determine if economic factors warrant the further study of the technology associated with the separation and use of these fission product elements.

SUMMARY

PROCEDURE

The market analysis of fission products Rh, Pd, Ru and Tc was divided into two major areas. First, a study was done of the supply and demand characteristics; second, an economic analysis of the profitability of separating and marketing these fission products was performed.

The supply and demand analysis considered the general market characteristics such as suppliers, the dependency of platinum metal supplied upon nickel and platinum demand, and the historic ratios of demand. A brief systems diagram outlined the multiple facets of the marketing problem. A mathematical model describing future consumption projections was outlined, and curves of consumption versus time were derived for Pd, Rh, and Ru. This enabled us to project the time period when shortages might occur.

The economic analysis consisted of defining a cost model using a present value analysis of net cash flows constructed to cover the period from 1975 to 2025. Various assumptions and costs were changed in the model to evaluate the effect on the value of the project. Ranges of profitability in terms of rate of return were calculated for various sets of assumptions.

CONCLUSIONS

It was concluded that a strong demand for palladium, and possibly ruthenium, will probably exist past the year 2000, but that rhodium demand will likely not exist past this time if platinum resources fail. Interim unsatisfied demand prior to that time is not likely unless the world political situation changes significantly. The minimum prospective rate of return required was estimated to be 15% due to the uncertainty inherent in evaluating the long-term nature of the projections, and the uncertainty of being able to initially penetrate the platinum metals market. To

achieve this return (1) the conceptual recovery plant must operate at 90% of capacity throughout its life with a recovery efficiency of 90%, (2) all recovered palladium must be sold the same year it is recovered and (3) the recovered ruthenium cannot be stored for radioactive decay longer than 10 years prior to sale.

Under current market conditions the requirement of having to sell fission product Rh, Pd and Ru initially is not likely to be met as long as natural sources continue to satisfy the demand. However, delaying the project 10 years could increase the prospective rate of return to 19% if projected prices and costs are realized. While current conditions do not appear favorable, new technology and rapidly changing market conditions could easily alter the present conclusion.

MARKET CHARACTERISTICS

Even though the platinum metals occur in very small concentrations (0.2 to 0.3 oz/ton) in natural ore,^(4,5) the valuable nature of these metals makes recovery profitable. Therefore, the roughly 90 oz/ton of Rh, Ru and Pd in spent nuclear fuel (burnup time 30,000 MWd/tonne)⁽⁶⁾ makes recovery potentially very attractive. There are three significant platinum-metals-producing countries accounting for 98% of total platinum metal production: South Africa, the U.S.S.R., and Canada. Only South Africa mines the platinum metals as the primary constituents in the ore. Canada and U.S.S.R. production is a by-product of nickel mining and recovery. The amount of platinum metals supplied, therefore, is partially dependent upon the demand for nickel. Since platinum is the primary product of the South African mines, the supply of palladium and ruthenium is also dependent to some degree on the demand for platinum. The South African producer, Johnson Matthey and Co., has avowed and pursued a policy of supplying enough platinum to meet increasing demand and thus maintain a steady market price.⁽⁷⁾ This producer has continually expanded output in recent years in order to adhere to this policy.⁽⁸⁾

One of the critical factors in the possible marketing of fission product Pd, Rh, Ru and Tc is time. As is discussed in the economic section of this report, the profitability of the project depends to a large degree on how soon the fission product metals can be sold. Because of the problems and hazards associated with them, they will probably not be sold, even at a discount, until the supply of natural platinum metals falls short of demand. This can occur in two ways. First, the overall resources can become depleted. This case is treated in the section on resource availability. Second, the ratio of demand for various platinum metals may vary from the ratio in which these metals are recovered. If the economics of recovery dictate, as seems to be the case, that platinum and nickel are primarily the metals which make further expansion profitable, then conceivably an unmet demand could exist for Pd, Rh, and Ru. In the past, stockpiling of Rh, Pd and Ru has occurred insofar as the demand ratio of platinum to these other platinum metals has been greater than the ratio of natural occurrence in the ores. However, as shown in Table 1, in recent years the demand ratio in the United States has shifted so that palladium comprises 50 to 60% and platinum 35 to 45% of demand. Table 1 also shows that the ratio of the platinum metals in the South African ore is roughly 70% Pt and 30% Pd and since Canada's contribution is minor, free world

TABLE 1. Comparison of Recovery and Demand Ratios
for Pt, Pd and Rh

	5-Year Average Demand Ratios in the U.S. (a,b)					Recovery Ratios ⁽¹⁰⁾		
	1947 -51	1952 -56	1957 -61	1962 -66	1967 -71	So. Africa	Canada	U.S.S.R.
Pt	53%	52%	40%	39%	41%	71%	43%	30%
Pd	40%	44%	55%	56%	53%	25%	43%	60%
Rh	--	--	3.0%	4.4%	3.5%	2.4%	3.0%	2%

(a) Ratios are calculated as a percent of total platinum metals sold in U.S.

(b) Calculated on the basis of information found in Reference 9.

platinum mining alone has not produced sufficient palladium to meet the U.S. demand. However, the U.S.S.R. with a Pd-Pt ratio of approximately 60:40 has been able to meet the increased palladium demand through their production and stockpile of palladium. Unless palladium demand increases significantly beyond 60% for total platinum metal production, Russia will likely be able to continue to meet demand until the palladium reserves are exhausted.

A similar, although not so severe case, may exist in regard to rhodium. Demand for rhodium in the U.S. averaged 3.4% of total platinum metals sold in the U.S. from 1958 to 1971. This compares to estimated percentage compositions of 3% in Canadian ore, 2% in Russian ore, and 2.4% in South African ore (Table 1). The higher demand for rhodium in the last 10 years has probably been satisfied by stockpiles accumulated prior to this period. The extent of rhodium stockpiling is not known, hence it is difficult to predict when an unsatisfied demand for rhodium may occur, but it is possible that such a condition may exist in the future.

Even if a rhodium shortage did occur, however, increased supplies or substitutes would not relieve the situation if a platinum shortage occurred simultaneously. In statistical correlation analyses, a 100% correlation indicates a cause-effect relationship. The correlation between rhodium and platinum demand during the period 1958 to 1969 was 93%, indicating a strong probability that Rh and Pt demand are related. This conclusion is strengthened by the fact that most of the known significant uses of rhodium in industry are as an alloying agent with platinum.

The high radioactivity associated with short-cooled, fission product rhodium and ruthenium will make it necessary to store these elements for 20 to 25 years before processing and sale as shown below:⁽³⁾

	<u>After Discharge</u>	<u>After 25 Years</u>
^{102m}Rh	290 $\mu\text{Ci/g}$	1.7 $\mu\text{Ci/g}$
^{102}Rh	1900 $\mu\text{Ci/g}$	---
^{106}Ru	400 $\mu\text{Ci/g}$	12 $\mu\text{Ci/g}$

This severely restricts profit potential because of the time value of money and, to a lesser extent, the storage cost. In terms of marketing, the storage period results in the rhodium and ruthenium being available for sale when current projections indicate an increased demand due to diminishing supplies of the natural metal. However, another implication of such a long storage period is that the planning and decision to carry out such a venture must be made far in advance of the time when the actual need arises. The uncertainty associated with such long-term projects make serious investor interest unlikely unless very large rates of return are involved.

POSSIBLE APPLICATIONS OF FISSION PRODUCT Pd, Rh AND Ru

The recent decisions by U.S. automobile manufacturers to use platinum-metals-based catalyst systems will markedly increase the demand for these metals. One such system, developed by Johnson Matthey,⁽¹¹⁾ employs what is termed a "promoted platinum metals catalyst." Previous systems for air pollution control have been platinum-based;⁽¹²⁾ however, the difference in terminology used indicates that other platinum metals may be used in conjunction with platinum. Below are listed other industrial applications according to the platinum metal used.

- Palladium

1. Telephone contacts
2. Addition to a silver alloy for hydrogen purification
3. Olifinic oxidation to produce acetone and methyl-ethyl-ketone
4. Hydrocyanic acid production through the Andrussov process
5. Hydrogen peroxide manufacture
6. Hydrogenation catalyst in pharmaceutical manufacture.

- Rhodium

1. Nitric acid manufacture (used with platinum)
2. Additive to palladium in hydrogen purification
3. With a plastic coating in computer core construction
4. Furnace winding (used with platinum)
5. Rh-Pt thermocouple
6. In crucible cladding and bushings in the glass industry (with platinum)
7. Spinnarets in textile industry (used with platinum)
8. Low voltage electromechanical switch coatings.

- Ruthenium

Increasingly large amounts of ruthenium have been used in the electrical and chemical industries during the last year. The exact applications in these industries are, as yet, unknown.

ANALYSIS OF THE MARKETING SYSTEM

The use of the fission-produced platinum metals falls in the category of substitutes for "natural" platinum metals. A wide variety of factors, ranging from the use of non-platinum metal substitutes to increased recycle, must be considered. Consequently, a matrix of interactions is involved. Figure 1 shows a graphical representation of factors which could influence the use of fission-produced metals.

FIGURE 1. System Diagram for Platinum Metal Supply and Usage

Figure 1 is a simplified model of the interaction network that may exist. It shows the natural resources as the main source of platinum metals although an increasingly significant amount is being recycled. Increased natural recycling decreases the need for substitutes. However, substitutes such as fission product platinum metals and others will probably represent an increasingly large source with the passage of time. The fission product metals may have to be recycled separately to avoid contaminating the supply of natural metals.

The influence of international conditions is a factor that should be considered along with recycle, etc. The U.S. imports virtually all the platinum metals from foreign sources and its reserves are very small compared to the annual consumption (see Table 2). This places the U.S. at the mercy of the world market which is dominated by the Soviet Union and the Republic of South Africa. In 1968 the U.S. consumed 44 and 66% of the world's palladium and rhodium, respectively, and at the same time the Soviet Union produced 73 and 53% of the world's production of palladium and rhodium, respectively. Any protracted loss of this source of platinum metals could have a severe impact on the U.S. economy and would induce increased recycling, substitution, and favor the future use of fission-produced ruthenium, rhodium, and palladium.

GENERAL RESOURCE OUTLOOK FOR THE U.S. AND WORLD

The resource adequacy of a nation and the world has advocates at both extremes. The optimists generally consider that even if there may be future resource scarcity, technological innovation will overcome the difficulties associated with resource depletion. This is largely the view of Barnett and Morse⁽¹³⁾ and Landsberg, Fischman, and Fisher.⁽¹⁴⁾ Walter R. Hibbard,⁽¹⁵⁾ former director of the U.S. Bureau of Mines, is less optimistic and has pointed out that increasingly heavy demands for many resources will heavily strain some mineral supplies and deplete others. Hibbard lists ways that technology can expand our resource base. Suggestions included were: more intensive exploration and discovery, improved mining practices, recycling of scrap and waste, and substitution. Hibbard's estimate of our nation's resource adequacy is less optimistic than Landsberg, et al.⁽¹⁴⁾ Kruger⁽¹⁶⁾ takes a more pessimistic view and shows that competition for the world's limited resources will intensify because: 1) rapid population growth continues in the less developed countries; 2) underdeveloped countries tend to imitate western industrialization; 3) per capita consumption in newly industrialized nations grows exponentially. Solutions to these problems were similar to Hibbard's⁽¹⁵⁾ but also included population control. Geologist Preston E. Cloud, Jr.⁽¹⁷⁾ gives geologic justification for the pessimistic view of the world's natural resource situation and points out that the ocean is not a "mineral cornucopia". Cloud⁽¹⁷⁾ predicts that the platinum (and presumably the other platinoids) reserves will be depleted by the turn of the twenty-first century.

AVAILABILITY OF NATURAL Rh, Ru and Pd

Platinum metals always occur together and are concentrated in basic or ultrabasic rocks with crystal abundances of less than $5 \times 10^{-7}\%$.⁽⁵⁾ The indicated reserves⁽¹⁰⁾ of the platinoids are shown in Table 2.

TABLE 2. World Platinoid Reserves

Country	Million Troy Ounces				
	Pt Metals	Pt	Pd	Rh	Ru
United States	3	2.2	0.01	0.03	0.005 ^(b)
Canada	16	6.9	6.9	0.5	1.4 ^(a)
Colombia	5	4.6	0.04	0.1	0.001 ^(c)
Republic of South Africa	200	142	50	4.8	1 ^(a)
U.S.S.R.	200	60	120	4	12 ^(a)
World	424	215.7	176.9	9.4	14.4

a. Reference 10

b. Reference 5, p. 87

c. Reference 5, p. 69

These data represent conservative estimates of the world's platinum metals reserves. The reserves of the individual platinum metal are based on the long-term average composition of ores taken from the various sources. It is difficult to determine how well these reserves are known; therefore, they should be considered rough estimates. Canadian platinum metals reserves are more easily checked because they are approximately proportional to the nickel reserves. Using the value of 800 million tons⁽¹⁸⁾ for the Canadian nickel reserves and an average platinum metals tenor of 0.02 oz/ton⁽⁴⁾ of nickel ore, the Canadian platinum metals reserves are estimated to be about 20 million ounces - in close agreement with the U.S. Bureau of Mines estimate.⁽¹⁾ A crude estimate of the South African platinum metal reserves can be made from the width of the Merensky Reef, which is well known.^(5,pp.39,40) Using very rough estimates of the length and depth, along with the width and an average platinum tenor of about 0.3 oz/ton of ore,^(5,pp.39,40) the estimated South African platinum metals reserves are estimated to be somewhere between 100 to 200 million ounces. This value also agrees fairly well with the

U.S. Bureau of Mines estimate. As far as can be determined, there is no verifiable estimate of the Soviet Union's reserves. The U.S. and Colombian reserves are of the order of the world's annual production of these metals⁽¹⁰⁾ and therefore are insignificant.

The probability of finding new and significant platinum metals ore bodies cannot be precisely determined. However, it should be mentioned that these ore bodies are found in well-defined geologic zones having basic igneous rocks.⁽¹⁹⁾ Canadian data⁽²⁰⁾ indicate that the probability of a significant exploration discovery of any kind is proportional to the amount of money spent and is decreasing exponentially with an approximate 2.5 year half-time. The 10- and 20-year average of the discovery probability in Canada will be respectively one-third and one-sixth of the 1971 probability. These probability estimates are consistent with the pessimistic view of the world's resource availability.^(15,16,17)

One platinum metal "find" in West Australia was reported⁽²¹⁾ in 1970. Sparse data⁽²²⁾ on this discovery suggest that the inferred amount of platinum metals in this find is very roughly about 40 million ounces or less than 10% of the world's estimated reserves. Even discoveries of this size do not significantly alter the long-range resource prospects of these platinum metals.

AVAILABILITY OF FISSION PRODUCT Rh, Pd, Ru and Tc

The projected range of availability of Rh, Pd, Ru and Tc from nuclear fuels as given by Deonigi, et al.⁽⁶⁾ is shown in Table 3. It is evident that the amount of palladium produced will be small compared to the current annual demand for natural palladium. Once serious resource shortages begin, fission product palladium would only be a temporary solution to the problem of finding substitutes.

Rhodium, ruthenium and technetium-99 present the opposite picture. By 1975 more fission product ruthenium will be produced than is currently consumed annually and by 1980, production of fission product rhodium will approximate current U.S. annual demand. Since very little technetium-99 is used currently, this element will be produced in considerable excess.

The total supply of fission product Pd, Rh, Ru and Tc-99 is, of course, limited by the amounts of uranium and thorium available for nuclear fuel.

TABLE 3. Annual Availability of Fission Product
Pd, Rh, Ru and Tc in (000) Troy oz/yr^(a)

	Pd	Rh	Ru	Tc
1970	0.77	0.51	2.3	0.93
1975	22-23	13-14	61-67	25-27
1980	55-75	30-42	145-201	57-70
1985	115-170	64-95	302-450	119-178
1990	214-328	110-176	524-801	204-311

a. The ranges given reflect the differences obtained from the different types of reactors.

PROJECTED WORLD DEMANDS FOR Ru, Rh and Pd

The purpose of a projection into the future is to gain insight as to what might be the course of events. In the case of this study, a projection of future demands and comparison with known resource reserves may give indications of resource inadequacy or possible depletion problems for the platinum metals. Likewise, projections of future market prices and costs of separation may give an indication of project profitability. However, it should be remembered that projections are often highly uncertain. Factors such as war, economic depressions, population growth rates, technological factors, etc., all make projections incorrect.

The cumulative consumption curve for a non-renewable resource will exhibit the familiar S-shape common to growth phenomena.⁽²³⁾ This curve increases with time and is asymptotic 1) to zero at the initial stages of resource consumption and 2) with total resources available as a resource depletion is approached. One equation that has been used⁽²⁴⁾ to describe such a curve and which is consistent with plotted data points is

$$Q_t = \frac{Q^\infty}{[1 + \exp \{k[T_{\max} - T]\}]} \quad (1)$$

where Q_t = cumulative consumption up to time, T

Q^∞ = total amount of resource available at the beginning of consumption

k = consumption rate constant in years⁻¹

and $T_{\max}$ = year of maximum consumption. The problem with respect to calculating Q_t is to estimate k , Q^∞ and $T_{\max}$.

The derivative of Equation (1) has a shape similar to the familiar probability curve shown in Figure 2. It is mathematically described by the equation

$$\frac{dQ_T}{dT} = \frac{kQ_{\infty}e^{kTm}}{(e^{2kT} + Ze^{kTm}e^{kT} + e^{2kTm})} \quad (2)$$

In this case T is taken as zero and integrated backwards in time to obtain Q_t or the total consumption up to time, T which represents the shaded area in Figure 2.

FIGURE 2. Sample Probability Curve

Alternatively, the value for Q_t can be estimated from the equation

$$Q_t = R(o) \int_0^{-\infty} e^{-kT} dT = R(o)/k \quad (3)$$

where $R(o)$ = consumption rate at time T and

k = consumption rate constant.

The area to the right of "T" is equal to the presently known reserves, Q_r , plus the undiscovered reserves, Q_u . A very crude estimate of Q_u is given by

$$Q_u = D(o) \int_0^{\infty} e^{-k'T} = \frac{D(o)}{k'} , \quad (4)$$

where $D(o)$ = current discovery rate for resource
and k' = discovery rate constant.

At least for the platinum metals $D(o)$ is not a continuous function, so Equation (3) should be used with caution. The total amount of resource available at the beginning of consumption is

$$Q_{\infty} = Q_r + Q_t + Q_u . \quad (5)$$

Since Q_u is uncertain, it may be informative to determine the influence of $Q_{\infty} T_{\max}$ for rhodium. Q_r was taken from Table 2 and Q_t was calculated with Equation (2) using rate constants of 0.06 and 0.08 years⁻¹. The results of these calculations are shown in Table 4. These data indicate that about 40% of the world's rhodium will be consumed in 30 to 45 years, even if the presently known reserves are doubled and that $T_{\max}$ is not a sensitive function of Q_{∞} .

TABLE 4. Times of Maximum Rhodium Consumption
(All Q's are in 000,000 of Troy oz)

$Q_r = 9.4 \times 10^6 \text{ oz}$ $R(o) = 7.6 \times 10^4 \text{ oz yr}^{-1} (1968)^{(14)}$					
$k = 0.06 \text{ yr}^{-1}$			$k = 0.08 \text{ yr}^{-1}$		
$Q_r + Q_t$	Q_u	$T_{\max}$	$Q_r + Q_t$	Q_u	$T_{\max}$
10.7	0	33 yr	10.3	0	29 yr
	5	40 yr		5	34 yr
	10	45 yr		10	38 yr

Equation (2) was used to project demand for Pd, Rh and Ru (see Figures 3, 4 and 5). Data points representing estimated actual world demand were plotted and are in reasonable agreement with the theoretical projection curve. No data were available for historical world ruthenium demand.

FIGURE 3. Yearly World Consumption Projection for Natural Palladium at a Growth Rate of 8%/yr

FIGURE 4. Yearly World Consumption Projection for Natural Rhodium at a Growth Rate of 8%/yr

FIGURE 5. Yearly World Consumption Projection for Natural Ruthenium at a Growth Rate of 8%/yr

Recently, the U.S. Bureau of Mines has estimated demands for platinum metals for the year 2000.⁽¹⁰⁾ A wide range of considerations was used to make these estimates which are shown for the palladium and rhodium data. It is interesting to note that the logistic curve estimates are in reasonable agreement with those of the U.S. Bureau of Mines. Both estimates indicate that 40 to 50% of the known palladium and rhodium reserves may be consumed in the period between 1968 and 2000. The logistic data indicate that about 13% of the known ruthenium reserves may be consumed in this period. These data suggest increasing world competition for the platinum metals and increasing scarcity, especially if large high-grade ore bodies are not found. These observations are consistent with the pessimistic view of the world resource situation.

THE ECONOMICS OF RECOVERY OF FISSION PRODUCT Pd, Rh, Ru and Tc

This phase of the study was undertaken to evaluate the economic justifiability of separating and marketing Pd, Rh, Ru and Tc. This phase was done by creating an economic model incorporating projected costs and revenues. This model was then used to analyze various operating conditions.

THE ECONOMIC MODEL

The economic evaluation was accomplished through the use of an economic model. The model was constructed to simulate the timing and amounts of cash flows from a 5 MT/day recovery facility built as an adjunct to a fuels reprocessing plant. A present value analysis was then performed on the cash flows to determine the range of profitability and rate of return on investment.

For purposes of ease in constructing the model, cash flows were changed at 5-year intervals. The model was made as flexible as possible so that various assumptions such as date of earliest sale of fission products, etc., could be altered and the effect on profitability determined. An outline of the model is shown in Figure 6.

FIGURE 6. Present Valued Cash Flow Model for Pd, Tc, Rh and Ru Recovery^(a)

a. For a brief discussion of the fundamentals of present value analysis see Management Accounting, by R. N. Anthony, R.D. Irwin Inc. 1956.

COSTS

Investment Costs

- Process Equipment Costs

The equipment costs were estimated at \$300,000 because of the lack of a precise conceptual design process.

- Storage Costs

Because the short-cooled ruthenium present will generate approximately 1700 kcal/kg/hr of heat and have high energy gamma radiation associated with its decay, the storage facility for storage of the Rh-Ru separation product will have to have provision for extensive cooling and heavy shielding. If a 1-year lag time is assumed between reactor defueling and the separation process, a vessel capable of storing 1 year's production of ruthenium and rhodium (4,300 kg) must have the capability of storing approximately 210,000 kCi. The amount of power generated by such a vessel would be on the order of 2 MW at the year's end. The assumed use of a single vessel which would be contained in the hot cell itself may be an oversimplification. If such a solution is practicable, then precautions must, of course, be taken to insure that accidental contamination of stored ruthenium with newly processed, short-cooled ruthenium cannot occur.

- Capital Costs for Plant

Complete plant costs were extrapolated from equipment costs using typical construction cost distributions for a remotely maintained fuel reprocessing plant.⁽²⁵⁾ The applicable fractional cost distribution and the corresponding estimated costs for the precious metals recovery plant are listed in Table 5. As shown in the table the total cost is \$5.62 million.

A nondepreciable capital cost of \$500,000 was assumed for the R&D needed to perfect the separations process and design the facility. A

TABLE 5. Construction Cost for Precious Metal Recovery Plant

	<u>% Material and Labor According to Long(25)</u>	<u>Estimated Cost</u>
Process Equipment	17.9	\$ 300,000
Piping Valves and Fittings	20.5	344,000
Instruments and Controls	5.6	94,000
Electrical Equipment	1.3	22,000
Special Equipment	5.3	89,000
Process Building with Services	28.7	481,000
Liquid Waste Disposal (not applicable)	5.6	---
Gaseous Waste Disposal (not applicable)	2.3	---
Laboratory and Administration	2.0	34,000
Fuel Storage (not applicable)	1.4	---
Service Facilities	3.1	52,000
Site Development	6.3	<u>106,000</u>
	TOTAL MATERIALS AND LABOR	1,522,000
Overhead	52	790,000
Storage Cost	---	<u>181,000</u>
Basic Plant Cost	---	2,493,000
Contractor Costs (% of basic plant cost)	25	<u>624,000</u>
		3,115,000
Design and Engineering (% of basic plant cost plus contractor cost)	20	<u>624,000</u>
	SUBTOTAL	3,743,000
Contingency (% of subtotal)	50	<u>1,872,000</u>
	TOTAL PLANT COST	\$5,613,000

working capital cost of \$100,000 was assumed to start operations. The latter cost was assumed to be recovered at the end of the time span of operation.

- Operating Costs

Operating costs used in the model included labor, reagent materials for separation, initial purification and final purification, short-term storage costs and variable overhead (utilities, etc.). Variable overhead was estimated at 25% of the total of all other operating costs. Labor costs were increased at a rate of 4% per year to allow for inflation. A fixed overhead cost of \$12,000 per month was assumed for maintenance.

- Other Costs

Depreciation Since the nature of the operation is such that the major revenue flows will occur 20 to 25 years in the future, it is advantageous from a tax standpoint to amortize the capital cost as little as possible during the early years of the operation. The straight-line depreciation method accomplishes this best and therefore was the method assumed in the model. The life of the plant was assumed to be 40 years, since a long plant life would also allow more depreciation to be charged against revenue flows in later years.

Taxes Taxes were estimated at 50% of the net income after depreciation. Tax advantages from loss carry-forward were assumed to be negligible.

Interest Interest does not appear as a cost in the internal rate of return calculations as the facility was assumed to be totally financed by equity capital.

REVENUE

The initial assumptions in determining the revenue were:

1. Prices were increased stepwise every 5 years such that prices in the year 2000 corresponded roughly to those predicted by the U.S. Bureau of

Mines.⁽¹⁰⁾ The time span of the projection covered 50 years from 1975 to 2025.

The market analysis shows that the available natural supply of Rh, Ru and Pd will begin to decrease shortly after the year 2000. It is assumed, therefore, that prices of those metals will begin to rise sharply following this period.

2. All Rh and Ru produced will be salable at the end of the required storage period. This was assumed to be 20 years for rhodium and 25 years for ruthenium.
3. All of the Pd recovered can be sold immediately.
4. A market for Tc can be developed by 1980 and all of the Tc recovered can be marketed at that time.
5. Selling prices of the fission product materials were assumed to be 20% less than those of the natural platinum metals from 1975 to 1985. This discount was assumed necessary in order to justify the assumption that Pd could be marketed before serious shortages of the metal occurred. Such a discount would be necessary to induce the industrial consumer to assume the extra risks and costs associated with using radioactive materials. As the supply of natural platinum metals decreases, however, less price incentive will be needed and the price discounts were therefore lowered to 15% from year 1985 to 2000, 10% from 2000 to 2015 and 5% from 2015 to 2025.

THE ANALYSIS AND RESULTS

After the economic model was constructed, a standard case was defined as a base for comparison. The effect of changing the cost variables on the present value of operation was then studied in order to determine the relative sensitivity to change. Those costs, which were discovered to be sensitive, could then be examined in more detail to increase their accuracy and hence the validity of the model. A knowledge of the cost sensitivities would therefore permit a better evaluation of the risk involved.

In deciding whether or not a variable was sensitive, the percent change in the variable was determined as a function of the absolute change in present value. A subjective, judgmental factor of the relative volatility to change of the variable was also used. For example, a 10% price change over the projected price changed the present value by \$2 million. In addition, the market price of platinum metals is subject to considerable fluctuation; hence, the variable was judged to be sensitive. Table 6 gives a list of the more sensitive variables in approximate order of their sensitivity.

TABLE 6. Sensitivity Analysis

Very Sensitive Variables

Return on Investment	This is the most sensitive variable in the analysis. Incremental upward shifts in the present value should result in increasing incremental rates of return.
Plant and Equipment	A \$1 change in cost results in approximately a \$2 change in present value. The magnitude of the costs causes the high sensitivity of this cost variable.
Year in Which Project is Undertaken	Delaying the start of the project 5 years to 1980 increases the present value by \$3.7 million. A delay of 10 years increases the present value by \$7.6 million. Construction costs were assumed to rise 8% annually in both cases.
Time of Sale of Products	This is a very sensitive variable. Of the four metals considered in the analysis, the sale time of Pd is the most critical because its low radioactivity makes it unnecessary to store it. The second most sensitive metal to sale time is Rh because of the large profit margin associated with it.

Sensitive Variables

Platinum Metals Separated	All metals contribute to project profitability. Pd and Rh contribute relatively more than Ru and Tc.
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TABLE 6. (contd)

Sensitive Variables (contd)

Price Changes	10% changes change the present value \$2 million.
Initial Concentrations in the Fuel	10% changes change the present value \$2 million.
Efficiency of Operation	10% changes change the present value \$2 million.
Efficiency of Metal Recovery	10% changes change the present value \$2 million.
Variable Overhead	100% changes change the present value \$2 million.

Relatively Insensitive Variables

(Region over which the variables were tested)

Costs of Temporary Storage (\$130/mo to \$13,000/mo)
Size of Labor Crew (from 8 to 26 personnel)
Maintenance (\$10,000/mo to \$15,000/mo)
Rate of Increase in Labor Costs (from 2 to 6% annually)
Initial R&D Cost (\$200,000 to \$500,000)
Working Capital Required (\$100,000 to \$500,000)

Because projections are, by their nature, subject to considerable nonquantifiability and hence risk, it is important to identify the risks and their magnitude as nearly as possible. From the sensitivity analysis, the variables with high risk factors are time of sale, capital costs, starting time of project, and rate of return. The time of sale is critical because it is determined by factors external to the investing company's control. The risk associated with capital cost arises from the large size of those costs and their irreversible nature. The year in which the project is started is important because, although the control of the variable lies completely within the company, there is risk associated with starting too early and not maximizing return or starting too late to maximize the share of the market captured. The rate of return variable has no risk associated

with it by itself, but since it is weighed against the risks inherent in the projection to determine the final decision, it becomes a critical factor in that projection.

Changes in price also materially affect the investment. The risk associated with the investment is dependent to a high degree on the price variable because of the difficulty in accurately forecasting market conditions for long periods into the future.

The evaluation of the relative value of each of the products showed palladium to be the most valuable of the individual products assuming that it could be sold immediately on recovery. All products contributed to the overall profitability, but technetium and ruthenium contributed least to the final present value and were, therefore, economically the least essential. The decrease in present value by eliminating ruthenium was only slightly over \$1 million. This represents the net contribution of ruthenium to the profitability of the project and the maximum amount that could be paid now for an external storage facility without decreasing the profitability of the investment.

The effect on profitability of the time of earliest sale was explored and the results showed that palladium and rhodium sale times were more critical than those of technetium and ruthenium.

In view of the long storage time associated with radioactive rhodium and ruthenium, the venture must be regarded as having a high risk factor because of the uncertainty associated with the sale of these products. Increasing this risk is the difficulty in initially penetrating the market. The very minimum prospective rate of return that firms would require under these conditions would probably approach 15% after taxes.

The sensitive conditions necessary to achieve this minimum return were determined to be the following:

1. All of the palladium separated must be sold beginning no later than 1975 (or immediately after the plant begins operations).
2. All of the rhodium separated must be sold beginning no later than 1985.

3. Recovery of the platinum metals must be 90% or better of the initial concentrations.
4. The plant must operate at an average of 90% of capacity.
5. Overhead will not exceed \$12,000/mo plus 10% of operating costs.
6. Investment costs will not exceed \$6,000,000 for total plant and equipment and \$500,000 for preliminary research.
7. Market prices at which the fission product platinum metals would be sold would rise corresponding to the following schedule.

	<u>Pd/gram</u>	<u>Rh/gram</u>
1975	\$1.13	---
1980	1.42	---
1985	1.70	\$ 7.30
1990	2.11	8.30
1995	2.41	8.88
2000	2.90	9.98
2005	3.47	13.02
2010	6.11	18.32
2015	6.11	18.32
2020	6.11	18.32

Delaying the project five years until 1980 would increase the rate of return under the above conditions by approximately 2% from 15 to 17%. A 10-year delay until 1985 would increase the rate of return approximately 4% from 15 to 19%.

If capital costs could be halved from \$6 million to \$3 million, the rate of return could be increased 8% from 15 to 23%; however, it is unlikely that such a cost saving could be achieved.

CONCLUSIONS

- The market survey shows that strong demand for the platinum metals, palladium, rhodium and possibly ruthenium will probably exist past the year 2000.

- Interim unsatisfied demand for palladium will probably not exist unless important new technology shifts palladium sales above 60% of total platinum metal sales, or supply from the U.S.S.R. fails. Nuclear source palladium will not be produced in sufficient quantities to satisfy demand if natural sources fail, hence other substitutes for natural palladium will be sought.
- Demand for rhodium could exist if recent market growth rates are maintained. However, this demand will likely not be maintained if platinum demand falls because most uses of rhodium are complementary to platinum.
- Large amounts of previously stockpiled ruthenium make marketing of fission product ruthenium improbable unless industrial uses continue to increase significantly.
- No industrially significant uses for technetium-99 are known at this time.
- The profit analysis indicates that the project could earn an estimated minimum return of 15% only if the marketing and operating conditions outlined on pages 25 and 26 of this report were to exist.
- The prospective rate of return of the project could be increased to 19% if startup is delayed until 1985 and if projected price and cost increases are realized.

In view of present market conditions, the project does not appear profitable and it seems unlikely that investors could be interested in the project at the present time. However, changing conditions such as new technology, increased market demands or hostility on the part of governments presently supplying the U.S. could rapidly reverse the present conclusion.

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