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ECONOMIC STUDY

OF

GEOTHERMAL STEAM PRODUCTION AND POWER GENERATION

HR

FOR

PHILLIPS PETROLEUM COMPANY

BY

ROGERS ENGINEERING CO., INC.
SAN FRANCISCO

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DISCLAIMER

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1. INTRODUCTION

This report presents the results of our study to determine the required selling price of geothermal flash steam in order for Phillips Petroleum Company to obtain a rate of return on investment of 10, 15 or 20 percent on its discovery in Nevada.

The economic evaluations are based on an order-of-magnitude type of estimate of capital costs for the flash steam production, steam gathering and brine reinjection system to supply steam to a 55 MW (Gross) geothermal power generating plant, using mixed pressure (double flash steam) turbine design.

Geothermal well costs, brine quality and well productivity data were provided by Phillips Petroleum Company and are based on the discovery wells in Nevada. Power plant costs are based on current technology and available hardware, under construction at the present time. Costs have been escalated to 1977.

2. SUMMARY

Based on resource temperatures of 400°F and well flow of 450,000 pounds of geothermal brine per hour per well, the flash steam must be priced at 10, 14 or 20 mills/kWh in order to achieve a rate of return on the investment for the production quantities of 10, 15 or 20 percent respectively.

The corresponding cost of power (electricity) at the power plant bus bar would be 24, 28, 34 mills/kWh.

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3. DESCRIPTION

A. General

The geothermal power plant, utilizes steam flashed from geothermal brine. A two stage flash system was chosen to maximize the power production for the given well flow. The design conditions used as a basis for the cost estimates are as follows:

Power Plant (Gross)	55 MW
Reservoir Bottom Hole Temperature	400°F
Wellhead Pressure	75 psig
Well Flow Each Well	450,000 lbs./hr.
Production Wells Initially Required, Including One Spare	17
Reinjection Wells Initially Required	8

B. Power Plant

The power plant consists of the powerhouse building which encloses the generating equipment and auxiliaries, the high voltage substation, and the cooling tower. The high voltage substation is located adjacent to the powerhouse. The cooling tower is located on the opposite side and downwind of the powerhouse with respect to the prevailing winds and at a sufficient distance to minimize the exhaust plume impingement on the powerhouse and the high voltage substation.

The equipment inside the power plant building consists of the turbine generator, low level direct contact condenser, hot well pumps, electrical switchgear, generator step-up transformer and associated mechanical and electrical auxiliary equipment.

The steam entering the turbine is condensed in the direct contact condenser. The hot water is pumped to the cooling tower by the hot well pumps and the cooled water is returned to the condenser assisted by gravity and the condenser vacuum. The amount of water evaporated in the cooling tower nearly equals the steam flow to the turbine. The excess is reinjected into the ground together with the flash waste water. Therefore, once the plant is started no additional cooling water is required.

C. Steam Gathering System and Reinjection Facilities

Hot water from the wells is transported by the wellhead pressure to the high pressure flash drum. Each flash drum, approximately 10 ft. in diameter and 20 ft. high, is fed by a maximum of four wells. The high pressure steam and hot water remaining from the first stage flash are piped separately to the powerhouse. The high pressure steam is fed to the turbine and the hot water to a single low pressure flash drum.

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The low pressure flash drum, approximately 20 ft. in diameter and 30 ft. high, is located near the powerhouse. The low pressure steam from the second flash is fed to the turbine and the remaining hot water from the flash drum is pumped directly to the reinjection wells.

A holding pond is provided at each high pressure separator for the hot water in case the low pressure flash drum is out of service. Pumps are installed at each holding pond so that the waste water can be pumped to the reinjection wells. A pump is also provided at the cooling tower for disposal of the blowdown into the reinjection system.

D. Production and Reinjection Wells

The production wells are spaced at approximately 1,000 ft. intervals. Seventeen wells are drilled initially to provide the required steam for the power plant. From previous experience it has been determined that the hot water flow from each well decreases with time until in approximately ten years it levels off to about one half the original flow. Therefore, additional wells are required to meet the power plant demand throughout the life of the plant. The well drilling schedule for the power plant requirements is shown in Table IV.

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The reinjection wells are drilled approximately 9,000 ft. from the power plant at the edge of the hot water field. Eight reinjection wells are required, with two extra wells drilled as spares in the beginning of the power plant life.

4. COST ESTIMATE

A. Power Plant

The power plant cost estimate was made using actual costs from previously built plants escalated to 1977 and from current data supplied by major equipment manufacturers. A summary of the installed cost is shown in Table I.

The current (first quarter 1977) installed costs of the major equipment used in the cost estimate are shown below:

Turbine Generator 55 MW Gross	$6,090,000
Condenser and Gas Removal Equipment	1,420,000
Hot Well Pumps	1,020,000
Cooling Tower	1,300,000

B. Steam Gathering and Reinjection Facilities

The cost estimate for the steam gathering and reinjection facilities was made from cost of the individual components. A summary of the installed cost is shown in Table II.

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C. Production and Reinjection Wells

The drilling cost of the wells was obtained from Paul English of Phillips Petroleum Company.

Production Well	(1977)	$488,000
Reinjection Well	(1977)	$435,000

5. ECONOMIC ANALYSIS

A. General

The economic analysis was made separately for the power plant and for the steam producing, gathering and reinjection facilities.

The power plant analysis developed the cost per kilowatthour based on the cost of the installed power plant excluding the price of steam.

The steam producing, gathering and reinjection facilities analysis developed the selling price of steam per kilowatthour, to provide various rates of return on investment.

By adding the two kilowatthour cost elements the rate of return on investment on the steam producing, gathering and reinjection facilities can be obtained for various electric power selling prices.

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B. Power Plant

The economic analysis of the power plant is shown in Table III. The power plant cost is the cost at start of operation in early 1981. Escalation of the 1977 cost was based on figures given in the next section.

C. Steam Production, Gathering and Reinjection Facilities

The results of the economic analysis of the steam producing, gathering and reinjection facilities are shown in Figure 1 which plots the selling price of steam versus the return on investment. Sample calculation for the rate of return are shown in Table IV.

The analysis was made using the present worth method wherein the return on investment is equal to that return which balances the present worth of the investment outlay and the present worth of the positive net cash flow.

The following data supplied in a telephone conversation by Paul English were used in the development of the economic analysis.

a.	Land Acquisition Cost	$152,500
b.	Annual Lease Rentals, Payable up to Time of Production	$ 61,200

c. Escalation

1977-1978	10.0%
1979	9.5%
1980	9.0%
1981	8.5%
1982	8.0%
1983-1986	7.5%

No escalation beyond 1986

d. 30% of well cost depreciable
70% of well cost intangible drilling cost

e. Three dry wells

f. Federal and State Income Tax 51%

g. Royalty Rate 10%

h. Gross Production Tax and Ad Valorum Tax 3%

i. Overhead Investment Cost, Excluding Land 1.65%

The following additional assumptions were made.

a. Wells and gathering system has 20 year life for accounting purposes.

b. Straight line depreciation

c. Life of field 35 years, which is the same as the power plant.

Investment tax credit was not used since it would balance the interest on the money spent before production starts.

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TABLE 1

CAPITAL COST SUMMARY
55 MW GENERATING UNIT (Note 1)
COST ESTIMATE

Account No. (2)		Dollars (Thousands)
311	Structures and Improvements	$ 3,500
314	Turbine Generator Unit, Condenser, Cooling Tower, Pumps, etc.	11,620
315	Power Plant Electrical Equipment	1,240
316	Miscellaneous Power Plant Equipment	580
353	Substation Equipment	610
	Total Direct Cost	$17,550
	Engineering and Construction Management	1,755
	Sub Total	$19,305
	Contingency 10%	1,930
	Sub Total	$21,235
	(3) Financing During Construction @ 9%	1,911
	Total Estimated Installed Cost (4)	$23,146

NOTES

(1) Generating Unit is 55 Gross MW
Net Output at Bus 51.5 MW

(2) Account Numbers include equipment in accordance with Federal Power Commission Publication UNIFORM SYSTEMS OF ACOUNTS PRESCRIBED FOR PUBLIC UTILITIES AND LICENSEES FPC A-118

(3) 24 month construction period. Financing during construction equal to approximately total cost for one year at 9%.

(4) Costs are for First Quarter 1977 (Escalated to 1980)?

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TABLE II

CAPITAL COST SUMMARY
STEAM GATHERING AND REINJECTION SYSTEM

GATHERING SYSTEM		
Piping		$2,651,000
Valves and Controls		279,000
Separators		940,000
	Sub Total	$3,870,000
REINJECTION SYSTEM		
Piping		$2,800,000
Pumps and Holding Ponds		276,000
Valves and Controls		92,000
	Sub Total	$3,168,000
	TOTAL ESTIMATED INSTALLED COST (Note 1 and 2)	$7,038,000

NOTES

(1) Costs are for First Quarter 1977
(2) Includes engineering and construction management, contingency and financing during construction

TABLE III

ESTIMATED COST OF POWER EXCLUDING FUEL COSTS

Fixed Charges	
1. Return and Depreciation	9.91
2. Taxes and Insurance	5.43
3. Sub Total (Fixed Charges)	15.34
Expenses	
4. Operation	0.55
5. Maintenance	0.80
6. General Expense	0.41
7. Total (Percent)	17.10
8. Estimated Construction Cost (1980)	$30,321,000
9. Net Capacity	51,500 kW
10. Capacity Factor Operation	80%
11. Net Annual Energy Production (Million kWh)	360.9
12. Cost Per Kilowatt ($/kWh) (Line 8 x Line 7)/(100 x Line 11)	0.014

NOTES

(1) Item 1 based on 35 year plant life using straight line depreciation and 9.5% return.

(2) Items 2, 3, 4, 5, 6 based on a California utility's application to the Public Utilities Commission for construction of a geothermal power plant.

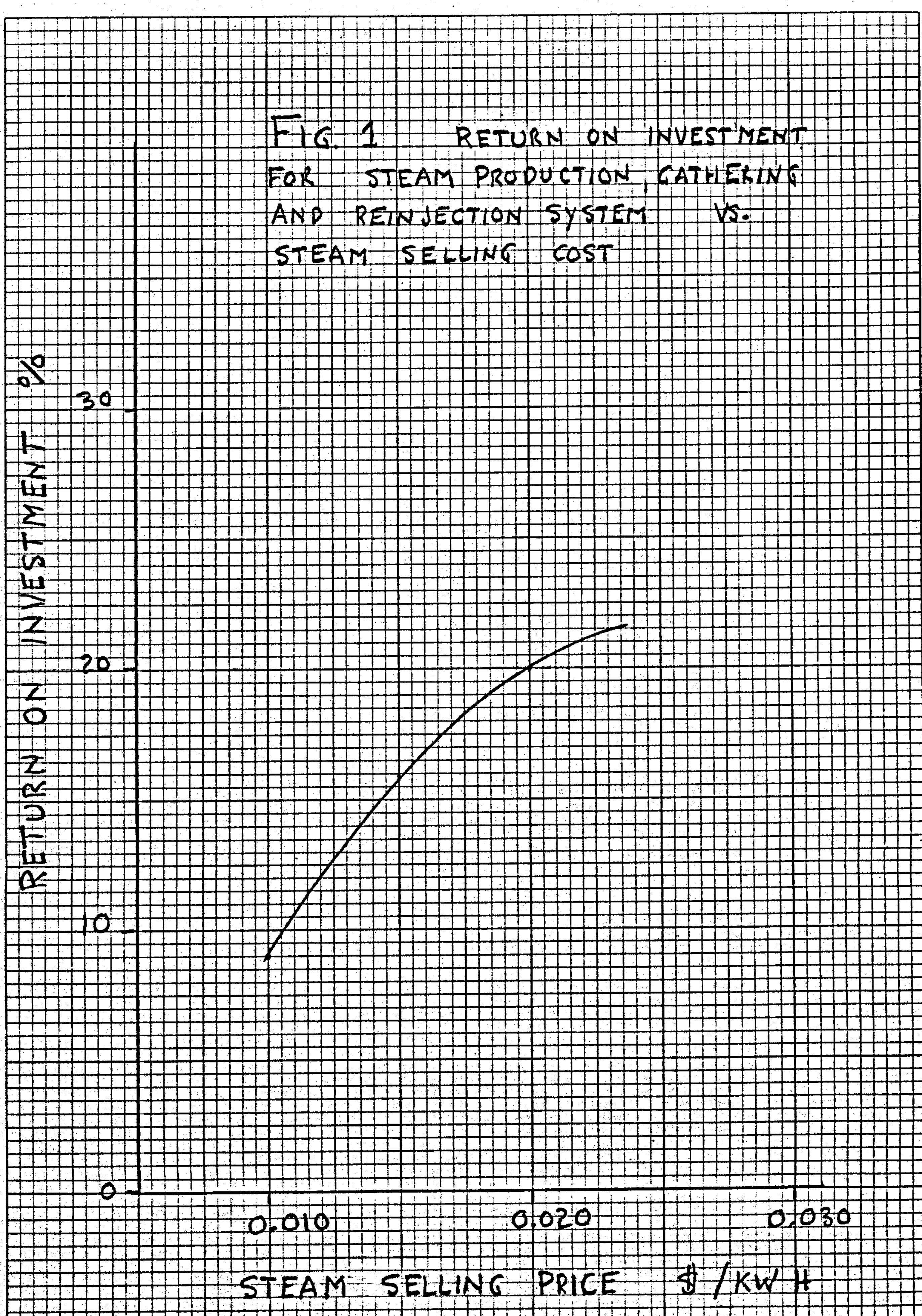

FIG. 1 RETURN ON INVESTMENT FOR STEAM PRODUCTION, GATHERING AND REINJECTION SYSTEM VS. STEAM SELLING COST
RETURN ON INVESTMENT %
30
20
10
0
0.010
0.020
0.030
STEAM SELLING PRICE $/KWH

FLOW PER WELL 450,000 LB/HR.

1ST QUARTER 1977 COSTS
PRODUCTION WELLS $ 438,000 ADD FOR PIPING 119,000
REINJECTION WELLS $ 435,000 ADD FOR PIPING 80,000 } FOR ADDITIONAL WELLS AFTER 1980
INITIAL GATHERING SYSTEM $ 7,038,000

COST OF DRY WELLS INTANGIBLE
70% OF WELL COST INTANGIBLE
30% OF WELL COST TANGIBLE

STRAIGHT LINE DEPRECIATION 20 yrs

TABLE IV

ROGERS ENGINEERING CO., INC.
ENGINEERS - ARCHITECTS
16 BEALE STREET
SAN FRANCISCO, CALIFORNIA 94105

ALL IN 1000's OF DOLLARS

START OF PRODUCTION (from 1981)

YEAR	ESCALATION FACTOR	WELLS DRY	WELLS PROD	WELLS REINJ	PRODUCTION WELL COST	PRODUCTION INTANGIBLE COST ①	PRODUCTION TANGIBLE COST ②	PRODUCTION ADD FOR PIPING ③	REINJECTION WELL COST	REINJECTION INTANGIBLE COST ④	REINJECTION TANGIBLE COST ⑤	REINJECTION ADD FOR PIPING ⑥	GATHERING SYSTEM ⑦	TANGIBLE COSTS ⑧	INTANGIBLE COSTS ⑨	1.65% OVERHEAD ON INVEST. ⑩ (1.65% x ⑧)	TOTAL TANGIBLE COSTS ⑪ (⑧ + ⑩)		FROM ⑨		
1976	0.81		1		395	277	118						152 (LAND ACQ.)	270	277	4	274		277		
77	1.00		4	2	1952	1366	586		870	609	261			847	1975	14	861		1975		
78	1.10	1	4	2	2684	2039	644		957	670	287			931	2709	15	946		2709	11,143	
79	1.20	1	4	2	2928	2224	703		1044	731	313			1016	2955	17	1033		2955	+ LEASE	COST
80	1.31	1	4	2	3196	2429	767		1140	798	342		9220	10329	3227	170	10499		3227		
81	1.43		2	1	1396	977	419	340	622	311	186	114		1059	1288	17	1076			= 11143	+ 305
82	1.54		2	1	1503	1052	451	367	670	335	200	123		1141	1387	19	1160			= 11450	
83	1.64																			= OPERATING	
84	1.78		2		1737	1215	521	423						944	1215	15	959			LOSS	CARRY OVER
85	1.91																				
86	2.05																				
87																					
88			2		2000	1400	600	488						1088	1400	18	1106				
89																					
90																					
91																					
92			2		2000	1400	600	418						1088	1400	18	1106				
93																					
94																					
95																					
96			2		2000	1400	600	488						1088	1400	18	1106				
97																					
98																					
99																					
2000			2		2000	1400	600	488						1088	1400	18	1106				
01 TO 03																					
004			1		1000	700	300	244						544	700	9	533				
05 TO 07																					
08			1		1000	700	300	244						544	700	9	533				
09-011																					
012			1		1000	700	300	244						544	700	9	533				
013-015	2.05																				
		3	34	10	26791	19274	7509	3814	5303	3454	1589	237	9372	23521	22733		22391				

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TABLE IV CON'T

ROGERS ENGINEERING CO., INC.
ENGINEERS – ARCHITECTS
16 BEALE STREET
SAN FRANCISCO, CALIFORNIA 94105

ALL IN 1000's OF DOLLARS

	(9)	(12)	(13)	(14) = (9)+(12)+(13)	(15) = 0.015 $/KW H × 51500 KW 80% OPERATING FACTOR	(16) = (15) × .13	(17) = (16) − (14)	(18) FROM PREVIOUS PAGE	(19) = (17) − (18)	(20) = (19) × .59 @51% TAX	(21) = (20) + (12)	(22)	(23) = (21) × (22) 15%	(24)	(25) = (21) × (24) 20%
YEAR	INTANGIBLE COSTS	DEPRECIATION	OPERATING COST	TOTAL EXP+DEP	GROSS INCOME	GROSS LESS 10% ROYALTY 3% GATHERING	NET INCOME	LOSS CARRY OVER	TAXABLE INCOME	AFTER TAX INCOME	NET CASH FLOW	PRESENT WORTH FACTOR – 15%	P.W NET CASH FLOW	PRESENT WORTH FACTOR 20%	P.W NET CASH FLOW
1981	1288	673	332	2293	5414	4710	2417	(2417)	0	2417	3090	0.870	2688	0.833	2574
82	1387	727		2446			2264	(2264)	0	2264	2991	0.756	2261	0.694	2075
83		785		1117			3593	(3593)	0	3593	4378	0.658	2881	0.579	2534
84	1215	785		2332			2378	(2378)	0	2378	3163	0.572	1809	0.428	1353
85		833		1165			3545	(796)	2799	2143	2976	0.497	1479	0.411	1223
86		833		1165			3545		3545	1737	2570	0.432	1110	0.335	861
87		833		1165			3545		3545	1737	2570	0.376	966	0.279	717
88	1400	833		2565			2145		2145	1051	1884	0.327	616	0.233	439
89		888		1220			3490		3490	1710	2598	0.284	738	0.194	504
90		888		1220			3490		3490	1710	2598	0.247	642	0.162	421
91		888		1220			3490		3490	1710	2598	0.215	559	0.135	350
92	1400	888		2620			2090		2090	1024	1912	0.187	357	0.112	214
93		943		1275			3435		3435	1683	2626	0.163	428	0.094	247
94		943		1275			3435		3435	1683	2626	0.141	370	0.078	205
95		943		1275			3435		3435	1683	2626	0.123	323	0.065	171
96	1400	943		2675			2035		2035	997	1940	0.107	208	0.054	105
97		998		1330			3380		3380	1656	2654	0.093	247	0.045	119
98		998		1330			3380		3380	1656	2654	0.081	215	0.038	101
99		998		1330			3380		3380	1656	2654	0.071	188	0.031	82
2000	1400	998		2730			1980		1980	970	1968	0.061	120	0.026	51
01		325		657			4053		4053	1986	2311	0.053	122	0.022	51
02		325		657			4053		4053	1986	2311	0.046	106	0.018	42
03		325		657			4053		4053	1986	2311	0.040	92	0.015	35
04	700	268		1300			3410		3410	1671	1939	0.035	68	0.013	25
05		247		579			4131		4131	2024	2271	0.030	68	0.011	25
06		247		579			4131		4131	2024	2271	0.026	59	0.009	20
07		247		579			4131		4131	2024	2271	0.023	52	0.007	16
08	700	247		1279			3431		3431	1681	1928	0.020	38	0.006	12
09		219		551			4159		4159	2038	2257	0.017	38	0.005	11
10		219		551			4159		4159	2038	2257	0.015	34	0.004	9
11		219		551			4159		4159	2038	2257	0.013	29	0.003	7
12	700	219		1251			3459		3459	1695	1914	0.011	21	0.003	6
13		191		523			4187		4187	2052	2243	0.01	22	0.002	5
14		191		523			4187		4187	2052	2243	0.009	20	0.002	5
15		191	332	523	5414	4710	4187		4187	2052	2243	0.007	16	0.002	5
	11,590✓	21298✓	11620	44508✓	189490	164,850✓	120,342✓			67391	88684		18990		14625✓

(26)	(27)	(28) = (27) × (11)
YEAR	PRESENT WORTH FACTOR 17%	P.W INVESTMENT
76	1.87	513
77	1.60	1338
78	1.37	1296
79	1.17	1209
80	1.0	10499
81	0.855	920
82	0.731	848
83		
84	0.533	511
88	0.284	314
92	0.152	168
96	0.081	89
2000	0.043	47
04	0.023	13
08	0.012	7
12	0.006	3
		17,800

(23) 18990 @ 15%
(28) − 17800
1190

(25) 14625 @ 20%
(28) − 17800
− 3175

RETURN ON INVESTMENT

$= 15\% + 5\% \frac{1190}{(18990-14625)}$

$= 15\% + 1.3 \approx 16\%$