CONTRACTOR REPORT

SAND82-7012
Unlimited Release
UC-66c

MASTER

A Forecast of Geothermal-Drilling Activity

DO NOT MICROFILM COVER

The BDM Corporation
1801 Randolph Road, S.E.
Albuquerque, NM 87106

Prepared by Sandia National Laboratories Albuquerque, New Mexico 87185 and Livermore, California 94550 for the United States Department of Energy under Contract DE-AC04-76DP00789

Printed July 1982

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Issued by Sandia National Laboratories, operated for the United States *Department of Energy by Sandia Corporation.*

NOTICE: This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government, any agency thereof or any of their contractors or subcontractors. The views and opinions expressed herein do not necessarily state or reflect those of the United States Government, any agency thereof or any of their contractors or subcontractors.

Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

NTIS price codes
Printed copy: A02
Microfiche copy: A01

SAND--82-7012

DE82 019202

NOTICE

Category UC-66C

PORTIONS OF THIS REPORT ARE ILLEGIBLE. It has been reproduced from the best available copy to permit the broadest possible availability.

SAND 82-7012

Unlimited Release

A FORECAST OF GEOTHERMAL-DRILLING ACTIVITY

Prepared by

A.J. Mansure and G.L. Brown
The BDM Corporation
1801 Randolph Road, S.E.
Albuquerque, New Mexico 87109

ABSTRACT

This report forecasts the number of geothermal wells that will be drilled to support electric power production in the United States through 2000 A.D. Results of the forecast are presented by 5-year periods for the five most significant geothermal resources.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

CONTENTS

	Page
Executive Summary	1
Introduction	5
Approach and Methodology	7
Establishing the Approach	7
Estimating Numbers of Wells	10
Time Dependence of Parameters	15
Estimating Wells in Unidentified Resource Areas	16
Data Review and Documentation	19
Parameters Used to Estimate Electrical Capacity	19
Parameter for Counting Wells	26
Results	37
Baseline Conditions	37
Uncertainty in Forecast	38
Sensitivity of the Results to Uncertainties	40
Appendix A - Computer Code	55
References	83
Distribution	85

A FORECAST OF GEOTHERMAL DRILLING ACTIVITY

Executive Summary

The purpose of this report is to estimate the number of geothermal wells to be drilled in the United States for each 5-year period to 2000 A.D. The report presents forecasts of the growth of geothermally supplied electric power. The report then quantifies the different types of geothermal wells needed to support the forecasted capacity.

The rate of growth of electric capacity at geothermal resource areas is expected to be 15 to 25 percent per year (after an initial critical size is reached) until natural or economic limits are approached. Five resource areas in the United States should grow to significant capacity by the end of the century (Figure 1). The best estimates of the number of wells that must be drilled in each 5-year period to support the electric capacity are given in Figure 2. About 5000 geothermal wells are expected to be drilled in support of all electric power projects in the United States from 1981 to 2000 A.D. The reported numbers include production, exploration, injection, and replacement wells and take into account drilling other resource areas. The Geysers area is expected to retain most of the drilling activity for the next 5 years. By the 1990s, the Imperial Valley is expected to contain most of the drilling activity with the result that half of the geothermal wells drilled in the next 20 years will be in the Imperial Valley.

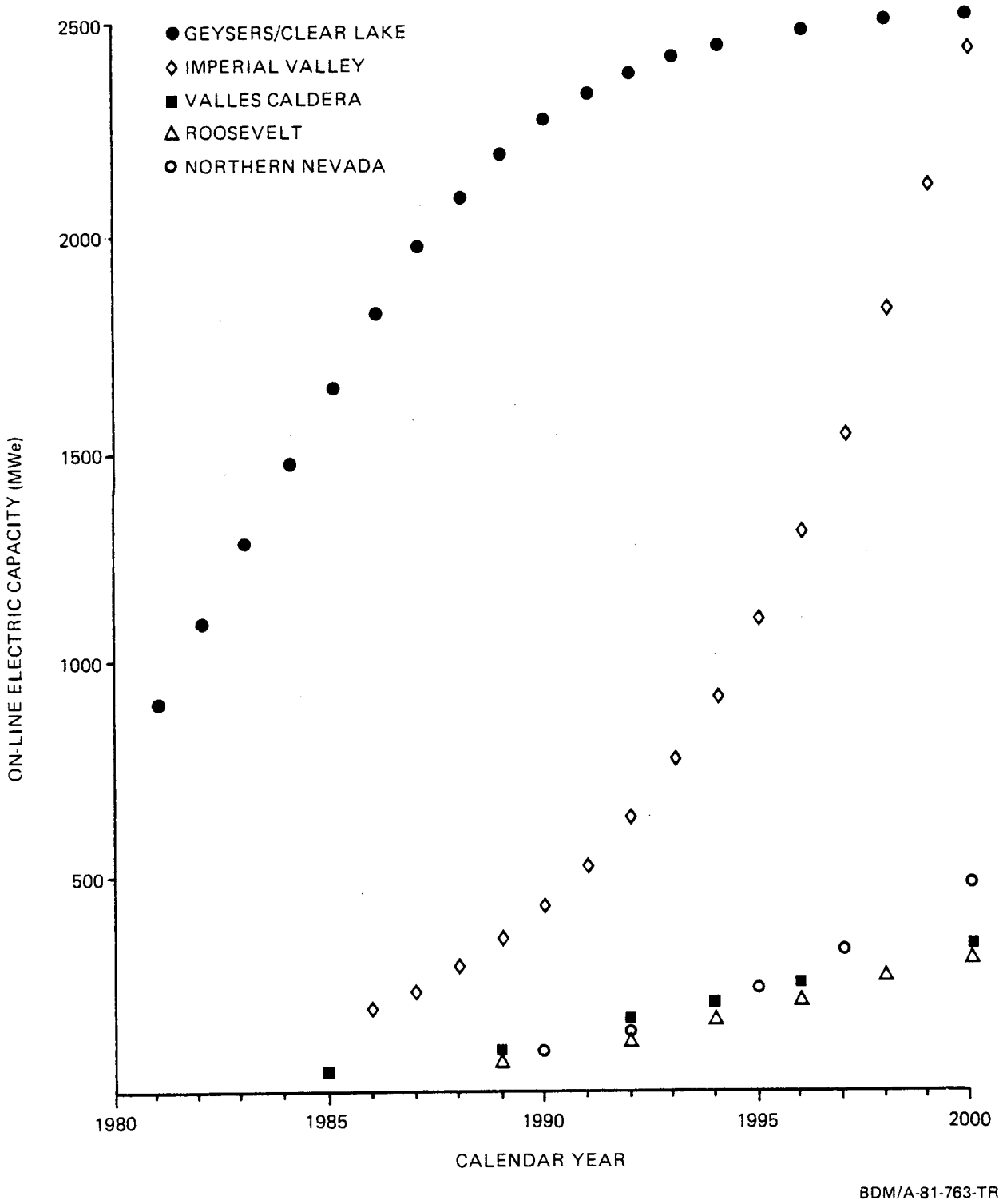


Figure 1. Forecast of Geothermal Electric Power Capacity

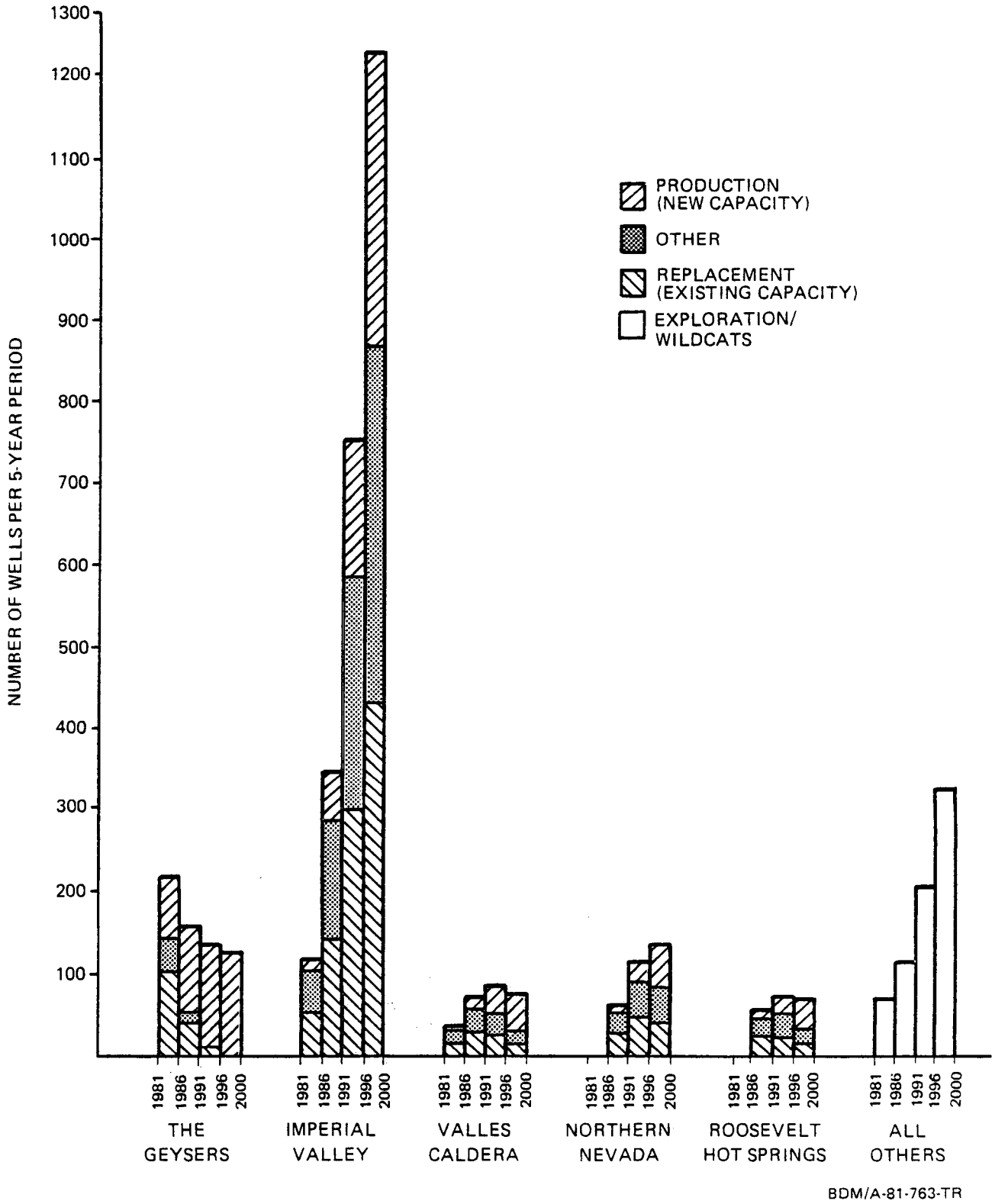


Figure 2. Numbers of Geothermal Wells

Introduction

This report is intended to supplement and update a previous report which presented a methodology for estimating geothermal drilling activity in specific areas of the United States.[1] Using available data, that report made best estimates of drilling activity in The Geysers, the Imperial Valley, Roosevelt Hot Springs, Valles Caldera, and Northern Nevada.

This report further refines and updates the data and methodology presented by Brown et.al.[1] An effort to document all sources of data has been made. The previous methodology has been refined by addition of time-dependent parameters, by accounting for wells drilled in undeveloped areas, and by making it possible to unambiguously account for wells drilled prior to the initial start of full-scale development.

In order that the methodology may be easily used for revised forecasts and sensitivity analysis, the authors of this report have written and implemented a computer code. The results in this report were obtained using the final version of the code, which is included at the end of this report.

It should be noted that the process of updating and refining the data and methodology did not result in any major revisions to any of the basic results or conclusions presented in the original report.[1]

Approach and Methodology

Establishing the Approach

The original work by Brown began with the gathering of data.[1] The data were examined (in terms of scope and detail) to see what type of methodology for forecasting numbers and types of wells the data could support. The data gathered indicated that any methodology developed would need to reflect three important features of the industry:

(1) Factors that influence drilling activity for electric power projects are quite different from the factors that influence drilling activity for direct heat projects.

(2) Drilling activity is correlated to growth in capacity, and the timing of the start of growth is highly dependent on the economic and institutional barriers associated with the resource.

(3) Once growth starts at a particular resource, it is likely to proceed quite rapidly. Hence any realistic methodology must treat resource areas separately since some are likely to grow to a large size before others start to grow at all.

The data on the direct heat industry were insufficient for development of a general methodology for forecasting numbers and types of wells. The methodology that was developed, and refined, in this report applies only to electric power projects.

The commitment to build a power plant in a given resource area is important because only a few wells will be drilled before the commitment to build is made since only wells in the vicinity of the first plant can be used right away. Where electric power generation from geothermal resources is economic, the number of wells drilled will be whatever the power plants require, not the other way around. Hence the methodology for forecasting the number of wells should reflect both the commitment to build power plants and the fact that electrical capacity drives drilling activity.

Based on the points above, one way of estimating geothermal drilling activity is to forecast each important resource separately; first by

forecasting the number of megawatts on-line at each of these resources and then by expressing the number of wells in terms of the megawatts on-line. Fortunately, for the practicality of this approach, a review of the data indicated that only five resource areas are likely to have significant growth in the next 20 years.* The five resource areas likely to achieve significant growth are The Geysers, Imperial Valley, Northern Nevada, Roosevelt Hot Springs, and Valles Caldera. After looking at the histories of development in different geothermal resource areas, and after considering the engineering involved in developing electric power capacity, a basic theory was developed which, although not elaborate, serves the purpose of estimating drilling activity to a sufficient degree of accuracy. The theory can be stated as follows:

After a period of exploration, reservoir development, and prototype power plant testing, the development of the reservoir area reaches a point where the risk of loss is less than the promise of profit. Start-work orders are made on the full-scale development of the resource, and growth may average as much as 25 percent a year for sustained periods of time (although an average growth of 20 percent a year is more likely which amounts to a doubling of capacity every 5 years). Growth of capacity eventually begins to slow and then stop as natural, economic, or political limits are reached. This theory of growth can be represented graphically as in Figure 3. Since capacity is added in chunks of perhaps 55 or 110 MW_e, the actual growth curve is a staircase. After the point in time (t_o), when the full-scale development begins, the staircase can be approximated by a smooth mathematical curve (as shown in the figure) which is accurate enough for our purposes.

*Significant growth is taken to mean growth that leads to at least a 5 percent share of drilling activity in any 5-year period.

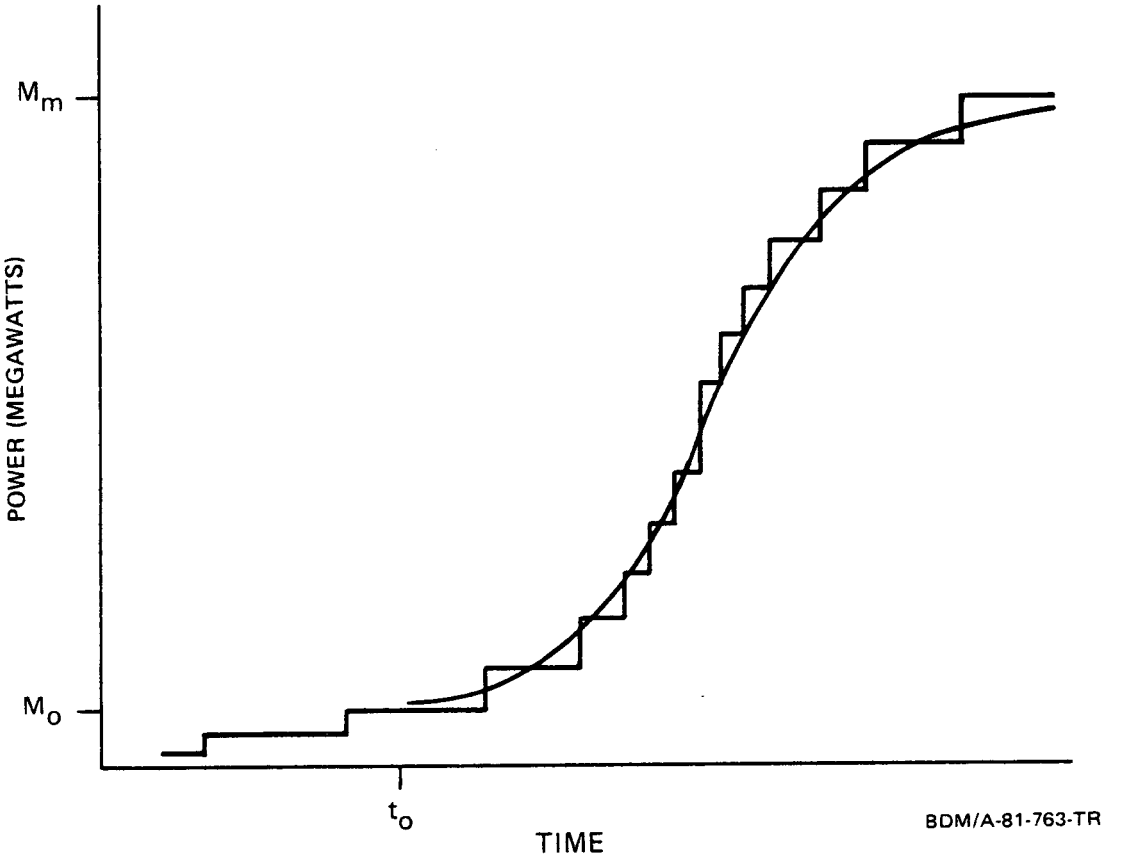


Figure 3. Assumed Development Scenario

The parameters required to establish the megawatts on-line curve are thus:

(1) t_o - the time when critical conditions for natural growth are met (called IYRGRW in the code presented at the end of this report).

(2) M_o - the number of megawatts on-line when natural growth begins (called IYRON in the code).

(3) K - the initial growth percentage (called GRWAT in the code).

(4) M_m - the maximum number of megawatts that can be developed at the resource (called RESPOT in the code).

Once the number of megawatts on-line is known for each year, the number of wells can be calculated if following parameters are known:

(1) P - Output per well measured in equivalent MW_e produced (called COEFWP in the code).

(2) r - drilling success ratio; the ratio of the total number of wells drilled including dry holes, exploration holes, and injection wells to the number of successful producers (called COEFTN in the code).

(3) R - well replacement rate; the ratio of the number of wells that must be drilled for replacing failed wells or replacing a decline in productivity to the number of the wells already on-line (called COEFRR in the code).

Table 1 presents the basic information used by Brown[1] to forecast drilling activity. Table 2 presents the revised data and parameter variations used in this report. Differences between the original data and the revised data are marked.

Estimating Numbers of Wells

Geothermal wells are drilled to (1) locate and define new reservoirs, (2) provide the production and injection wells required by new plants, and (3) replace depleted wells at existing power plants. The number of new wells (1 and 2 above) for a given reservoir will be proportional to the rate of growth of generating capacity (dM/dt) of that reservoir. The number of replacement wells (3 above) for a given reservoir will be proportional to the electrical generating capacity on-line (M) at the reservoir.

Table 1

Well Counting Parameters of Original Study

Resource	Initial Size[1] (M_o)	Initial Wells[2]	Growth Starts (t_o)	Productivity[3] (P)	Replacement Rate[4] (R)	Success Ratio[5] (r)	Maximum Size[1] (M_m)	Initial Growth[6] (K)
Geysers/Clear Lake	900	---	1981	7	.044	2	2500	20
Imperial Lake	200	50	1986	4	(.044)[7]	2	7000	20
Valles Caldera	50	15	1983	3	.033	2	400	20
Northern Nevada	100	20	1990	5	(.044)[7]	(2)[7]	1200	20
Roosevelt H.S.	70	15	1989	5	(.044)[7]	(2)[7]	400	20

[1] MWe

[2] Already drilled

[3] MWe per production well

[4] The fraction of the wells that must be replaced each year. Note: for a 15-year well life and an assumed 30-year project life, each well will have to be replaced once, and the replacement rate will be 0.033. The 0.44 rate corresponds to a 13-year well life.

[5] Total wells divided by production wells

[6] Percent per year

[7] Numbers in parentheses are estimates that are not backed by any actual data

Table 2

Revised Well Counting Parameters

RESOURCE	TIME INVARIANT Maximum Size (MWe) M_m	Initial Size (MWe) M_o	Growth Starts (Year) t_o	Growth Rate (%) K	TIME DEPENDENT Productivity (MWe/Well) P	Success Ratio r	Well Replacement Rate R
The Geysers	1200	900	--	15	6	1.2	.030
	2500		1981	20	7	1.4*	.050*
	3200		--	25	8	1.6	.112
Imperial Valley	4000	200	1985	15	3	1.5	.057
	7000		1986	20	4	2.0	.069*
	9000		1987	25	5	2.5	.086
Northern Nevada	600	100	1989	15	4	1.5	
	1200		1990	20	5	2.0	.061*
	1800		1991	25	6	2.5	
Roosevelt H.S.	--	70	1987	15	4	1.5	
	400		1989	20	5	2.0	.061*
	1000		1991	25	6	2.5	
Valles Caldera	200	50	1984	15	3	1.5	
	400		1985*	20	4*	2.0	.061*
	--		1986	25	5	2.5	

*Value revised from previous estimate.

The number of new wells required each year will be the increase in capacity on-line (ΔM) divided by the productivity per well (P), all multiplied by the ratio of the total number of new wells drilled to the number of successful production wells (r), i.e.,

$$\text{New Wells} = \frac{r}{P}\,\Delta M. \qquad \text{(Eq. 1)}$$

Estimates of P, the average productivity per well in megawatts, can be made from actual well tests (well flow rate, temperature, and fluid quality) on individual wells; or the estimates can be based on historical information as to the number of production wells drilled per megawatt of capacity for a typical plant in the field being evaluated. The ratio of total wells drilled to the number of successful production wells, r, must be based on historical data on drilling in the reservoir being evaluated. On the average, the new wells are expected to be drilled about 3 years before the new electrical capacity is due to come on-line.

The number of replacement wells required will be the capacity on-line (M) times the replacement ratio (R) times the ratio of the total number of new wells drilled to the number of successful production wells (r) all divided by the productivity per well (P), or

$$\text{Replacement wells} = \frac{rRM}{P}\ . \qquad \text{(Eq. 2)}$$

R, the replacement ratio, is determined from historical data on the fraction of wells that must be replaced each year to sustain production. The replacement wells, on the average, are expected to be drilled about 1 year before they are needed.

In addition to estimates of the coefficients (r, R, and P), estimates of the number of new wells and replacement wells require that the generating capacity (M) be forecasted as a function of time. After successful demonstration, a geothermal electric power project should grow rapidly until natural, economic, or political limits are approached. The capacity has been assumed to grow from an initial critical value (M_0) at a rate initially proportional to the capacity on-line, but at a rate that

decreases as the maximum resource capacity (M_m) is approached according to

$$\frac{dM}{dt} = \frac{k}{M_m} M (M_m - M). \qquad \text{(Eq. 3)}$$

M_o, the initial critical capacity, is estimated from the size of typical geothermal power plants and the development plans of the local utilities. M_m, the maximum resource capacity, is a function of the geology of a reservoir. The solution to the above differential equation for the growth of capacity is

$$M = \frac{M_m}{(M_m/M_o - 1)e^{-kt} + 1} \quad . \qquad \text{(Eq. 4)}$$

The "effective growth constant", k, is evaluated from the initial growth percentage (K) and the above differential equation. For example, assuming an initial growth percentage of 20 percent

$$0.2 = \frac{\Delta M}{M} = \frac{\Delta t}{M_o} \left. \frac{dM}{dt} \right|_{t=o} \quad ; \Delta t = 1 \text{ year}$$

or rearranging and substituting into equation 3

$$\left. \frac{dM}{dt} \right|_{t=o} = 0.2M_o/\text{year} = \frac{k}{M_m} M_o(M_m - M_o)$$

and solving for k,

$$k = \frac{0.2M_m \ /\text{year}}{M_m - M_o} \quad . \qquad \text{(Eq. 5)}$$

If needed, the number of wells yet to be drilled before the reservoir reaches critical size is calculated according to:

$$\text{initial wells} = (\tfrac{1}{2})\,\frac{rM_o}{p} \qquad \text{(Eq. 6)}$$

The (½) factor was assumed to correct for wells drilled during the exploration and feasibility stages of development.

To better indicate the level of accuracy of this methodology, all numbers of wells have been rounded off to the nearest 5 or 10.

Time Dependence of Parameters

The following parameters were considered as potentially time dependent: P, R, r, and k; whereas M_o, M_m, t_o, and the initial delay periods are point estimates of parameters that are basically time invariant. The parameters P, R, and r enter into calculations only through multiplying by M or ΔM to get a resultant number of wells (see Equations 1 and 2). Since M and ΔM are calculated separately each year, it is easy to use current or time dependent values for P, R, and r. The code does this automatically when given initial values of these parameters and coefficients of their power series time dependence.

Incorporating time dependence of k into the model is a bit more difficult. When k changes in time, the equation must be modified so the exponent in the denominator of Equation 4 is

$$-\int_0^t k\,(t')\,dt' \qquad \text{(Eq. 7)}$$

Such an effect (while readily programmed) was not included in the code. This is because the differential Equation 3 and the resulting solution Equation 4 already incorporate a change from normal exponential growth in that it has a growth rate that slows down as the maximum capacity is reached. In view of the fact that the model already incorporates a variable growth rate, the addition of a time-dependent k would be redundant. Furthermore, the resulting refinement in terms of precision attainable with time-dependent k would greatly exceed the total accuracy of the forecast and the availability of data to check the forecast.

Estimating wells in Unidentified Resource Areas

A number of geothermal wells will be drilled in resource areas other than the ones identified for significant growth before 2000. However, the number of wells drilled in exploration or demonstration areas is likely to be only 10 to 20 percent of the total. The trend for developed resource areas to dominate drilling is illustrated by data from the 1970s. As shown in Table 3, for 9-1/2 years from January 1970 to June 1979, about 55 percent of all U.S. geothermal wells were drilled in The Geysers, the only developed area of the decade. The 45 percent share of drilling in undeveloped areas is expected to decline for reasons given below.

Table 3

Drilling Activity in the 1970s

LOCATION	# WELLS	%
Developed Area		
The Geysers	192	55
Areas Developing Before 2000		
Imperial Valley	68	20
Northern Nevada	21	6
Valles Caldera	18	5
Roosevelt Hot Springs	9	3
Exploration Areas		
Other Areas	38	11

Three independent arguments point to less than a 30 percent share for drilling in undeveloped areas, with a best estimate of about 20 percent. Because of high drilling success rates, high well productivity, and the need for only a minimum number of injection wells at The Geysers, only about one half as many wells are required per power plant at The

Geysers as at other typical geothermal areas. If one assumes twice the number of wells in The Geysers than actually exist and recalculates the percentage of wells in areas undeveloped as of 1979, the answer is 29 percent. The tendency for developed areas to dominate drilling activity will be enhanced when Imperial Valley, Roosevelt Hot Springs, Northern Nevada, and Valles Caldera join the list of developed areas since they require a higher number of wells than The Geysers. Note in table 3 that during the 1970s, only 11 percent of all wells were drilled in "other" areas, i.e., exploration areas or areas not expected to reach critical development criteria before 2000.

The second argument that drilling in undeveloped areas will not continue to be 45 percent starts with the observation that the growth of geothermal generating capacity averages about 10 percent per year according to Brown.[1] For 5 years, from January 1975 to January 1980, about 100 wells were drilled in undeveloped resources (i.e., outside The Geysers). Assuming the number of exploratory and development wells keeps pace with growth in capacity on-line, then 1500 such wells would be drilled between 1980 and 2000 A.D. Compared to the 4000 wells in developed areas, this number of exploration and development wells would be 27 percent of the total.

It may also be argued that exploration and development drilling was an unusually large fraction of all geothermal drilling in the 1975 to 1979 period. Or, in other terms, the fraction of the reservoir developer's operating budget that was being sunk into unproven versus proven fields was uncharacteristic of an industry operating at and for a profit. For operators with a history of production at The Geysers, rather than ones just entering the geothermal market, the percentage of wells drilled in undeveloped areas varies from 13 percent to 27 percent depending on the years selected.

Assuming 20 percent of the total drilling activity would be in undeveloped fields, then a total of 20 percent of (4000/.8) or 1000 wells would be drilled outside the developed areas.

Data Review and Documentation

Parameters Used to Estimate Electrical Capacity

There are four parameters used in the model that serve to define the total electrical capacity and how it changes over time. These can be categorically divided into parameters defining initial conditions and parameters defining growth. The initial conditions are given by initial electrical capacity, M_0, and initial time at which growth begins, t_0. The conditions for growth are given by the initial annual growth rate, K, and maximum sustainable electrical capacity, M_m. The data and sources to support estimates of these four parameters are discussed below.

In our original report we estimated a year t_0 in which an average steady growth of electrical capacity would begin in each resource area. In every case, a minimum t_0 can be estimated fairly accurately from a basic time lining of required events. The maximum t_0 is more difficult to estimate. In fact, we cannot say with certainty that electrical capacity of any resource area other than The Geysers will begin to grow in this century. However, factors (such as changes in regulations) that shift t_0 for one resource area will often shift t_0 in the same direction for other resource areas as well. In any case, if t_0 is delayed at any set of resources, the effect would be to lengthen the period of domination of drilling at The Geysers.

For The Geysers, t_0 is fixed. We can estimate a minimum and a probable t_0 for the other resource areas based on available data and historical trends.

The minimum t_0 is derived from simple time lining of events. The starting point is the "present stage of development". The end point is the "decision to proceed with full-scale development". The minimum times for each event in the series is given in Table 4. In the best case, 5 years are required from the time the first well is spudded until full-scale development starts.

Many factors can combine to lengthen the minimum times given in Table 4. Generally, the most important factors can be found under the

Table 4

Events Leading to Full-Scale Development

EVENT	TIME (YEAR)
Demonstrate Availability of Steam	
Drill Development Wells	.5
Flow Test	.5
Feasibility Demonstration	
Construct Model Plant	.5
Operate Plant	.5
Prototype Plant	
Construct	2
Operate	1

headings "Institutional Barriers" and "Economic Constraints". Already, various factors have combined to cause considerable delays at Roosevelt Hot Springs, Valles Caldera, Northern Nevada, and the Imperial Valley.

The Imperial Valley has advanced to the stage of having several demonstration plants. If major construction were to begin in January 1982, then the earliest t_0 would be 1985. Our best estimate is that this schedule can be achieved with only minor slippage, and we estimate a t_0 of 1986. It would take some serious circumstances to push t_0 beyond 1987. Any such circumstances are judged to be unlikely, or very unlikely if they affected t_0 only in the Imperial Valley. In any event, such circumstances are unforseeable and any attempt on our part to forecast such events would be specious.

Roosevelt Hot springs has reached the feasibility demonstration stage. Phillips Petroleum has begun experiments with a mobile, 1.6-megawatt generator and Utah Power and Light has begun construction of a 20 MW_e demonstration power plant which could be on line as early as 1983[2]. According to Table 4, this would mean an earliest t_0 of early 1987. However, Utah Power and Light may not meet this time schedule. Licensing delays are also probable, as impacts on agriculture in the nearby valley will have to be studied and law suits are a distinct possibility. Because of the complex nature of the reservoir, the test phase may be abnormally long. For these reasons, we give 1989 as a best estimate for t_0, with a possible t_0 as late as 1991.

Valles Caldera is at about the same stage of development as Roosevelt Hot Springs. One reference gave a best estimate of 1983 for t_0.[3] This early date was selected because Union planned to skip the feasibility stage and proceed with a prototype plant. Recent adverse events have occurred which make 1983 a minimum t_0 and cause 1985 to be the best estimate. If events make t_0 slip beyond 1986, then no reasonable basis for forecasting is possible.

Northern Nevada is at the beginning of the feasibility demonstration phase. A consortium of five companies (NORNEV) has filed an application that seeks permission to build a 10-MW_e demonstration plant at Beowawe

KGRA within 2 years.[4] Assuming this occurs in 1982, then 1986 is the minimum t_0. The uncertain economics of most of the promising Nevada resource areas is likely to delay t_0, however. It is difficult to pinpoint specific reasons for delay, but the potential backers of geothermal electrical capacity in Nevada seem to have adopted a wait-and-see attitude. If success is achieved in other areas, development is likely to proceed. This implies a start on a prototype plant in 1986 (the year the Imperial Valley is expected to enter full-scale development) and a subsequent best estimate for t_0 of 1990 (assuming 1 year of slippage). Assuming the worst-case delays in other areas implies a worst-case t_0 of 1991 for northern Nevada.

The cases of The Geysers and Cerro Prieto suggest that long-term rates of growth in a viable resource area can be expected to range from 15 to 20 percent per year in the stage of development called "rapid growth towards limiting factors". In an especially favorable set of circumstances, growth at rates as high as 25 percent per year may be possible.

The basic contention of Brown with respect to growth of generating capacity was that an estimate of growth for the entire geothermal industry cannot be amortized over the known resource areas.[1] Each area will follow a basic pattern of (1) proof of feasibility, (2) rapid growth towards limiting factors, and (3) a period of near constant size as limits area reached. These features are revealed by analysis of growth at The Geysers and Cerro Prieto.

Data on growth at The Geysers are given in our original report (Table 3).[1] Using the equation

$$M = M_0(1 + K)^t \qquad \text{(Eq. 8)}$$

(where M is generating capacity, t is years, and K is growth rate), the growth rate (K) over any period ($t_2 - t_1$) is given by

$$K = e^z - 1 \qquad \text{(Eq. 9)}$$

where

$$z = \frac{\ln M_2 - \ln M_1}{t_2 - t_1} \quad . \qquad \text{(Eq. 10)}$$

Table 5 shows actual growth at The Geysers using the above method of determining growth percentage. Data on capacity at Cerro Prieto was obtained from Mexican sources[5] and Table 6 shows the results for growth using Equation 9.

Table 5

Growth at the Geysers

YEAR	CAPACITY (MWe)	% GROWTH BY DECADE (YEARLY AVERAGE)	% GROWTH FOR 3 DECADES (YEARLY AVERAGE)
1960	11	26[1]	20
1971	184	19[1]	
1980	908	10[2]	
1990	2404		

[1]Actual

[2]Projected

Table 6

Growth at Cerro Prieto

YEAR	CAPACITY (MWe)	% GROWTH (YEARLY AVERAGE)	% GROWTH (YEARLY AVERAGE)
1973	75		
		0	
1978	75		16
		32	
1984	400		

The maximum generating capacity, M_m that can be achieved in a given geothermal resource area is ultimately bounded by the heat content of the reservoir. In practice, however, M_m may be more severely bounded by institutional or economic constraints. Table 7 gives estimates of maximum generating capacity based upon reservoir heat content,[6] and also gives estimates of achievable capacity after consideration of limiting factors.

The Geysers/Clear Lake area has various plans that total 2.4 GWe by 1988.[6] However, the Clear Lake area (.9 GWe) is questionable in that it has not been proven that economic resources of commercial size exist there. Moreover, the uncertainties in the parameters used to calculate the total available heat in The Geysers indicate that the reservoir might support only 1.2 GWe for 30 years, so 1.2 GWe was chosen as a lower bound on capacity. The expected capacity of 2.5 GWe was selected because it represents the sum of the best estimates for the Geysers (1.6 GWe) and Clear Lake (0.9 GWe), and is close to announced development plans. An upper bound of 3.2 GWe on generating capacity was chosen because the total available hydrothermal energy may be somewhat greater than the best public estimate, and also because deeper portions of the reservoir may be exploitable through improved drilling technologies.

Table 7

Maximum Generating Capacity of Five Geothermal Resource Areas

AREA	GW_e FOR 30 YEARS				
	POTENTIAL[1]	LIMITING FACTORS	STUDY ESTIMATE LOW	EXPECTED	HIGH
The Geysers and Clear Lake	3	None	1.2	2.5	3.2
The Imperial Valley Salton Sea Westmorland Brawley East Mesa Heber	7	Possible Institutional or Economic	4.0	7.0	9.0
North Nevada Steamboat Springs Desert Peak Beowawe	1	Economic	0.6	1.2	1.8
Roosevelt Hot Springs	1	Possible Institutional	0.4	0.4	1.0
Valles Caldera	3	Institutional or Economic	0.2	0.4	0.4

[1]USGS Circular 790, reference 6

The available hydrothermal energy to a depth of 3 kilometers in the Imperial Valley has been estimated as sufficient to support 7 GWe of generating capacity.[6] However, there are several reasons to believe that the upper limit on generating capacity may be less than 7 GWe. First, a potential capacity of about 1 or 2 GWe may prove difficult to exploit since it is under the Salton Sea. Second, the presence of 7 GWe of capacity in the Imperial Valley could have an unacceptable impact upon the economically important agriculture of the area and upon the ecology of the valley.

Various numbers have been reported for the size of the Baca Location resource. The estimated size in MWe for 30 years is 2700.[6] Estimates of 410 MWe, 939 MWe, and 1246 MWe were reported for the resource in the Redondo Creek area of the Baca Location.[3] The 410 MWe estimate is based on pressure decline, caused by the mass withdrawal to date. The 939 MWe and 1246 MWe are based on recovery of heat in the rock by reinjected fluid using 18 percent and 5 percent as the porosity. The wells drilled at the Baca Location through 1979 have been the least productive in MWe/well of the five geothermal resource areas noted as likely to have significant growth in the next 20 years. Outside of the Redondo Creek area, commercial production has not yet been proven. Since 1979, few of the wells drilled have produced commercial quantities of steam. Hence, the most reasonable size for the Baca Location reservoir appears to the smaller of the numbers estimated, 410 MWe.

Parameters for Counting Wells

The model for drilling activity contains five parameters that are used to count wells once the generating capacity, M, and the yearly change in capacity, ΔM, are estimated. The first three parameters are well productivity, P, ratio of the total number of wells drilled to successful production wells, r, and the yearly replacement rate for old wells, R. Two of the parameters are of less importance since they effect the timing of wells, but not the total number of wells. They are the average number of years new wells must be drilled before the new

capacity comes on line and the average number of years that replacement wells must be drilled before they are needed. The data and sources to support estimates of these five parameters are discussed below.

The average productivity, P, for wells in a given resource area must be estimated before the number of wells needed to support additional electric capacity can be calculated. In Brown, the authors used 7, 4, 3, 5, and 5 MWe for average well productivity in The Geysers/Clear Lake, Imperial Valley, Valles Caldera, northern Nevada, and Roosevelt Hot Springs, respectively.[1]

In the Geysers, the present average steam production per well is 150,000 pounds per hour. Since 13 production wells are needed to supply steam for a 110-MWe plant, the average well contributes 8.5 MWe.[7] On the other hand, other data imply averages of 6.2 to 6.4 MWe for production wells supporting two different plants at the Geysers.[8,9] Based on this data, 7 MWe is a reasonable baseline estimate. Although technological improvements in well drilling and completion might serve to keep the average P for The Geysers near 7 MWe until the year 2000, no data were found to support a scenario which would result in an average MWe per well that would be higher than 7 MWe. Since new capacity is likely to be sited in areas that are less productive than the original fields, any trend is expected to be toward lower average P.* Because of the uncertainties, no time-dependent P in The Geysers has been postulated.

In the Imperial Valley, 12 production wells are planned for a 45-megawatt plant, which implies P = 3.8 MWe.[7] A planned 28-megawatt plant proposes to use seven existing and seven planned production wells, which implies a P of 2 MWe.[10] Based on the data, a choice of P = 4 for a

*Note that the effect of declining reservoir productivity on existing wells does not lower average P in our model. This effect is accounted for in well replacement ratio R. However, declining productivity in developed areas may have an indirect effect on average P in new areas.

baseline in the Imperial Valley is reasonable, especially if improved technologies are considered. Four MWe is roughly equivalent to a flow of 500,000 pounds of fluid per hour for the typical Imperial Valley well. A P of 5 is a likely upper bound on what is possible to achieve, whereas a P of much below 3 would require so many wells as to render the projects uneconomic.

Data on the productivity of wells at Roosevelt Hot Springs are sketchy. One well was flow tested and estimated to produce 12.5 MWe and another well was flow tested and estimated to produce 4.5 MWe.[11] The 4.5 MWe well is probably more typical of the field. The occasional very good producer might move the average P upwards to some extent. Based on the available data, 5 MWe per well is a reasonable baseline.

A typical production well at the Baca Location in the Valles Caldera is expected to produce at least 2.9 MWe.[3] The existing four producers yielded an average of 3.9 MWe in flow tests.[3] Based on the data, 4 MWe is a best estimate.

To be economically competitive, the productivity of wells in northern Nevada geothermal fields must average somewhat better than the Imperial Valley. However, even the best resources in Nevada are inferior in quality to The Geysers. Since no data were obtained, a P of 5 was selected as a best estimate. This value is better than the P = 4 at the Imperial Valley and worse than the P = 7 at The Geysers.

As discussed above, the number of production wells needed to support new electrical capacity can be estimated from average well productivity, P. However, the other deep wells that must be drilled to achieve and support the production wells must also be considered. These "other" wells include abandoned, suspended, observation, and injection wells. The ratio of total (other plus production) wells to production wells is always greater than 1, and is labeled r in the model. In Brown, an expected value of r = 2 was used for each resource area.[1]

When a rig is working, the well is generally designated as a production, injection, workover, step-out, wildcat, or observation well. After the rig leaves, the well is usually redesignated as a production, suspended, abandoned, injection, or observation well. It is the "after drilling" categorization that is used to estimate r. The data presented

below (Table 8) are taken from articles by Republic Geothermal personnel in the Geothermal Energy Magazine.[12]

Table 8

Wells by Category in Three Areas
(Jan 1976 - Dec 1980)

Resource Area	Category					r
	Prod.	Susp.	Abd.	Inj.	Obs.	
The Geysers	121	28	11	0	3	1.35
Imperial Valley	43	3	1	9	5	1.42
Nevada	9	12	2	0	20	4.8

The data in the table above are not proper samples to provide good estimates of r for the Imperial Valley or northern Nevada,* but The Geysers data are relevant and yield an r equal to 1.4 after a slight upward correction for injection wells.

We can make another estimate of r for The Geysers by noting that electrical capacity increased by 650 MWe from 1972 to 1980. From 1970-1979, 193 wells of depth greater than 2000 feet were drilled at The Geysers.** Some of these wells were drilled to support previous or future capacity, but the remainder were drilled to support the 650 MWe. Since the average productivity of a well at The Geysers is about 7 MWe, then 90 wells were needed for the added 650 MWe. The remaining 103 wells cannot all be ascribed to the "other" category. Some will become production wells for future capacity. Some are replacement wells for existing capacity. But if about half the remaining wells are "other" wells, then we obtain r = 1.4.

*Since the data are from undeveloped areas, they cannot be taken at face value as necessarily representative of r during development.

**Data from Petroleum Information Company.

The r value in the Imperial Valley is likely to be higher than the 1.4 estimated for The Geysers because of the necessity for numerous injection wells. Plans for a 45-megawatt binary plant call for 12 production and 6 injection wells[7] which implies $r \geq 1.5$. Plans for Union's Brawley plant call for four production, four injection, and one alternate well[13] for $r \geq 2.2$. Hence $r = 2$ for the Imperial Valley is a reasonable estimate. In practice, r might turn out to be as low as 1.5 or as high as 2.5 in the Imperial Valley.

Estimates of r for northern Nevada, Roosevelt Hot Springs, and the Valles Caldera are difficult to justify at their current stages of development. The first 18 deep wells in the Valles Caldera have yielded about 33 percent production wells (after adjusting for exploration outside the main reservoir) for an r of 3.[3] Union Geothermal's own projections indicate a future r value of 2.[3] Of the first eleven deep wells at Roosevelt Hot Springs, seven were considered producers for an r value of 1.6.* The r value for recent drilling in Northern Nevada appears to be > 2.[12] From an economic standpoint, $r > 3$ is likely to be incompatible with profitabilty and growth. On the other hand, $r < 1.5$ for these three reservoir areas is a success ratio that is not likely to be achieved.

The number of replacement wells that must be drilled each year is a fraction (R) of the wells on-line (calculated from capacity on-line, M, divided by well productivity, P, times the ratio of total number of wells drilled to number of successful wells, r). This fraction (R) which we have called the replacement rate, is determined by both the mechanical well life and the productive well life. Mechanical well life is determined by such things as cement and casing failures, while productivity well life is determined by reservoir depletion, formation plugging, etc. Well lives make sense only in the context of stated reservoir characteristics, and they require historical data to be accepted with confidence.

Typical mechanical well lives are expected to range from greater than 25 years at The Geysers[14] to 10 years for the Imperial Valley.[15] In

*Data obtained through private communication with Phillips Petroleum personnel associated with the project.

the Imperial Valley the expected well lifetime due to corrosion is very dependent upon selection of casing (grade and type) and the cement job. Tests have indicated corrosion rates that imply well failures after from 4 to 20 years. Cement failures in wells range from 10 to 50 percent of the wells in different fields,[14] but most of these failures can be fixed by squeeze jobs or can be minimized in developed areas by proper well design. Cement failures generally occur at the beginning of the well life and are taken into account in this study by the ratio, r, of total number wells drilled to the number of successful wells drilled.

The other factor that affects the replacement rate is declining well productivity as a function of time. Several geothermal fields have been producing long enough for production decline to be observed. Elliot Zais has reported monthly fractional declines of 0.003, 0.01151, and approximately 0.00925 for Wairakei, The Geysers, and Cerro Prieto.[16] Chester Budd has calculated production decline rates as a function of well spacing for The Geysers.[17] For 5-acre spacing, his rates are about the same as Zais while for 20-acre spacing, Budd calculated 0.00495. Considering that recent strategy has favored larger well spacing and that Zais' estimates may be biased by smaller spacing and older data, Budd's 20-acre estimate is probably the most representative estimate of expected future production declines. For 45-acre spacing, Budd calculated 0.0031.

Production histories for fields in the Imperial Valley are very short, so less historical data are available. However, well tests have established reservoir properties from which decline effects can be inferred. At least two effects will contribute to production decline: 1) time dependent drawdown plus interference, and 2) poorer well performance because of pressure and temperature decline. Using properties representative of the Heber and East Mesa reservoirs and 20-acre spacing, these effects were calculated to produce monthly fractional declines of about 0.0018 and 0.0027 respectively. In addition to these effects, near-well bore damage or pore plugging increases the rate of decline.

The two well life factors (productivity and mechanical) can be combined to determine the yearly replacement rate according to the following equation.

Yearly Replacement Rate =

productivity replacement	+	mechanical replacement
[.8*YRDF*(1 + ½ YMFF)]	+	[.8*FOPAF * YMFF]

where YRDF = Yearly Reservoir Decline Fraction
YMFF = Yearly Mechanical Failure Fraction
FOPAF = Fraction of Original Well Production at Failure

The .8 factor takes into account that at the beginning of the project 20 percent excess steam is assumed and that this excess does not have to be replaced at the end of the project. The fraction of original wells that mechanically fail each year (YMFF) can be calculated from

$$\left\{\frac{PL-WL}{WL}\right\}\left\{\frac{1}{PL}\right\}$$

where PL = power plant life, WL = well life. The fraction of replacement wells that fail is one-half the value of this expression, since (on the average) the replacement wells are on-line for only one-half of the total plant life. The contribution of original wells to replacement is multiplied by the average productivity at failure since only this residual productivity at mechanical failure must be replaced. This average is

$$\frac{1}{WL}\int_0^{WL} e^{-\kappa t}dt$$

where κ is the yearly reservoir decline fraction.

Table 9 gives replacement rates calculated from the mechanical well lives and yearly reservoir decline rates presented above. For The Geysers, Table 9 gives an expected replacement rate as well as a high and low value plus time dependent values. The time-dependent numbers assumed initial replacement wells are for wells with 30-year mechanical life times and 20-acre spacing. As the field becomes fully developed the

Table 9

Replacement Rates

	WELL LIFE (YEARS)	YEARLY RESERVOIR DELINE	R	R(t)
The Geysers	30	0.037[1]	.030	
	25	0.059[2]	.050	.048 → .08
	25	0.138[3]	.112	
Imperial Valley	17[4]	0.054	.057	
	10	0.039[6]	.069	.086 → .057
	10	0.054	.086	
Others	15[5]	0.06[5]	.061	

Project life = 30 years.

[1]40-acre spacing.

[2]20-acre spacing.

[3]5-acre spacing.

[4]Resulting from improved technology

[5]Typical expected numbers.

[6]Based on a productivity index of 3000 (lbm/hr)/psi instead of 1000.

spacing is reduced to 10-acre. For the Imperial Valley the time-dependent value is based on the assumption that wells presently being drilled will last only 10 years; but as drilling and completion technology improves, the well life will be increased to between 15 and 20 years (17 used for calculations).[15] For the other areas only an expected value is reported in Table 9; for sensitivity studies the high and low values and time-dependent numbers reported for Imperial Valley can be used.

The lead time for well drilling depends upon the time to drill, test, and lay the surface piping as well as the need to have sufficient proven capacity available to justify construction of a plant. Typical times needed to drill a well, including an expected number of delays and problems, is 70 days.[18] Three months is usually plenty of time for testing a well. Surface piping can generally be installed in half a year. Therefore, measuring lead times in whole years, 1 year is a reasonable lead time for replacement wells.

A new 50-megawatt power plant typically requires 10 wells. This means, even using only one rig, 24 months is enough time to drill the wells. For new wells, the surface piping and testing adds additional complexity, but this work can continue during the final drilling. More important than how long it takes to drill the wells is the need to prove the reservoir sufficiently to justify the construction of the power plant and the need to fit well drilling into the permitting process. For the Baca project, the reservoir development program (not the exploration or proof of reservoir drilling programs) was planned to begin 3 years before the plant was scheduled to be on-line.[3] At The Geysers (for a typical plant) half of the wells are drilled 2 years before the plant is to go on-line.[19] Also, at The Geysers the time from the initial discovery well until the power plant is on-line is 6 years.[7] Three years is thus a reasonable estimate of lead time to use for new wells recognizing that the lead time in our study is to be an integer.

Changing the lead times shifts the point when the wells are drilled, but not the number of wells that are drilled. The total wells drilled from the year 1980 to 2000 depends upon the lead time to a minor extent because wells are shifted from before to after the year 2000. The 1-year lead time for replacement wells is probably fairly constant, but the lead time for new wells may vary from 4 years to 1 year.

Results

Baseline Conditions

The number of megawatts of geothermal electrical power production on-line each year until 2000 A.D. is presented in Figure 1 for each of the five resource areas where significant growth is expected. The points on this figure were calculated by the code presented in the next section of this report and using the data presented in Table 2. Figure 1 shows that for the next 10 years The Geysers will continue to grow rapidly and be the dominant geothermal resource, producing 75 percent or more of the geothermal electric power on-line. After the year 1990, growth at The Geysers will slow down as development reaches the maximum size of the resource. During this same time period power on-line at the Imperial Valley will grow rapidly, but over the next 20 years will not grow to the point where the size of the resource will slow additional development. In the year 2000 The Geysers and Imperial Valley are expected to have about equal amounts of power on-line. For the next 20 years, resources outside California are expected to grow enough to achieve only 20 percent of geothermal power production.

For The Geysers, Valles Caldera, and Roosevelt Hot Springs, Figure 1 shows that the most important factor governing total growth in the next 20 years will be the size of the resource (M_m). For these resources, Figure 1 is not very dependent upon initial size (M_0), time when natural growth begins (t_0), or the growth percentage (K). For the Imperial Valley and northern Nevada resources, size will not be a limiting factor in the next 20 years; instead the initial condition (initial size and time when natural growth begins) and the growth rate will determine power on-line as a function of time.

Figure 2 shows the number of new production, replacement production, and other types of wells (injection wells, dry holes, and exploration wells) expected to be drilled in each resource by 5-year periods. The figure also shows the number of wells (mostly exploration) that are expected to be drilled in areas other than the five resources that are

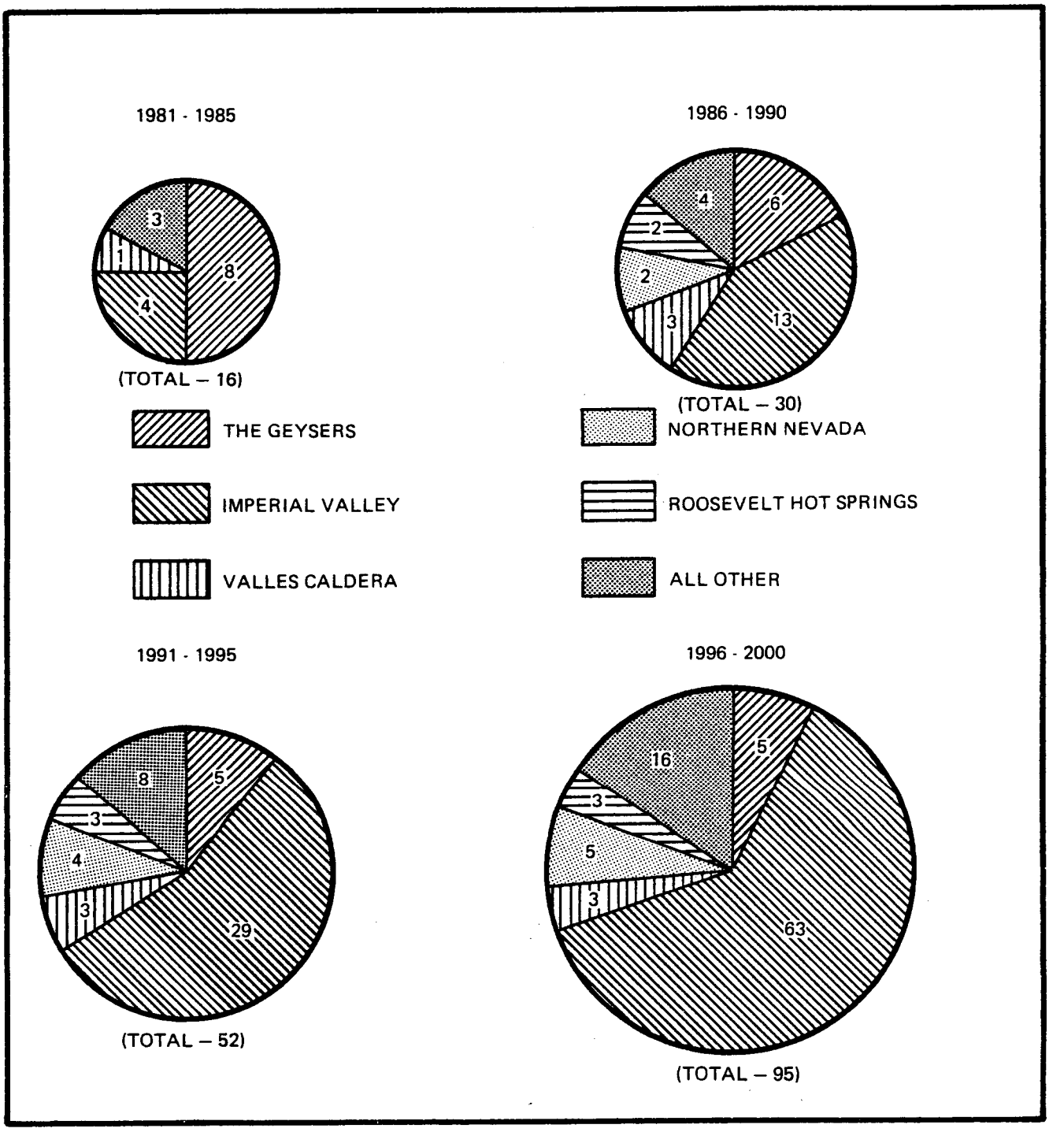
predicted to grow significantly. For the next 5 years, 50 percent of the wells will be drilled in The Geysers. For the next 20 years, there will always be more wells drilled at The Geysers than at Valles Caldera or Roosevelt Hot Springs, but after 10 years the number of wells drilled in northern Nevada will exceed The Geysers. After about 1988, drilling in the Imperial Valley begins to dominate with over 50 percent of the activity.

After 10 years, Figure 2 shows that drilling in "other" areas will surpass drilling in any of the five areas except the Imperial Valley. The five areas explicitly shown on Figure 2 are forecasted to reach critical conditions for natural growth before 1990. The resources lumped together in "all others" are not expected to reach critical conditions for natural growth before 1990, although small plants (10 MWe) may be built before 1990 to demonstrate feasibility; e.g., Coso. The figure shows that the number of wells forecasted for "all others" is consistent with these assumptions.

The number of rigs required to drill these geothermal wells is shown in Figure 4. The determination of the number of rigs required was made using the number of wells reported on Figure 2 and an average time of 70 days per well. This time was not based on optimized drilling, but assumes a normal amount of trouble.[18] The number of rigs grows from 16 for the next 5 years to 95 for 1996 to 2000; on Figure 4 the total number of rigs required is represented by the size of the circles.

Uncertainty in Forecast

To understand how uncertainties in the parameters used in this forecast affect the number of wells expected to be drilled, it is helpful to divide the parameters into two groups. First, there are the parameters required in Equation 4 to determine the number of megawatts on-line. These are initial size, initial growth percentage, maximum size of the resource, and the time when natural growth begins. The latter is only implicit in Equation 4 since it is when Equation 4 starts measuring time. The importance of these parameters or the effect of uncertainty in one of



BDM/A-81-763-TR

Figure 4. Number of Drilling Rigs Required

these parameters is interrelated to the values of the other parameters in the group.

An examination of Figure 1 shows that for The Geysers, Valles Caldera, and Roosevelt Hot Springs a change in the maximum number of megawatts will affect the number of wells drilled. On the other hand, changes in the other three parameters (initial size, initial growth percentage, and the time when natural growth begins) will have little or no effect on the total number of wells drilled at these areas. If the maximum size of these resources is larger, then the total number of wells will increase by the same percentage.

For the Imperial Valley and northern Nevada, the number of wells drilled is not affected by changes in the resource size but is affected by the initial condition (initial size and time natural growth begins) and the initial growth percentage, cf., Figure 1. An increase in initial size or initial growth percentage increases the number of wells drilled at the Imperial Valley and northern Nevada resources. Increasing the time when natural growth begins causes wells that would have been drilled before 2000 A.D. to be drilled after 2000 A.D., and hence an apparent reduction in the number of wells drilled at these resources occurs.

The second group of parameters is those that convert from megawatts on-line to the number of wells: output per well, drilling success ratio, and well replacement rate, cf., Equations 1 and 2. The effect of these parameters upon the number of wells drilled is either a direct proportionality (replacement rate and drilling success rate) or an inverse proportionality (output per well). An understanding of the effects of uncertainties in these parameters can be ascertained from the properties of proportionalities.

Sensitivity of the Results to Uncertainties

Since Figure 2 shows that The Geysers and Imperial Valley are the two resources that will dominate geothermal drilling, uncertainties in forecasting the number of wells in these resources are more important than uncertainties in forecasting the number of wells in the other

resources. Therefore, the rest of this section concentrates on The Geysers and the Imperial Valley. The important uncertainties are thus the size of The Geysers resource; growth rate for the Imperial Valley and, for both resources, the uncertainties in the parameters that determine how many wells are required to produce the forecasted power on-line.

Geysers--Figure 5 shows the forecasted power on-line at The Geysers for resource sizes of 1200, 2500, and 3200 MWe, the values of Table 2. The figure shows that if the resource is larger than the expected size of 2500 MWe it will be 7 or 8 years before the additional drilling activity occurs. On the other hand, if the resource capacity is only 1200 MWe, the impact on drilling would be apparent in 3 years. Three years is a short enough time that, when coupled with the development plans upon which applications for permits have been filed (1750 MWe), if the resource were only 1200 MWe this limitation should have already become apparent. Hence, we are led to believe the minimum size of the resource must be more than 1200 MWe and closer to 1750 MWe. (Figure 5 shows that 1750 MWe should be reached in about 7 years.) Figure 6 shows the number of wells that must be drilled to develop 1200, 2500, and 3200 MWe at The Geysers.

Figures 7 and 8 show the forecast of the number of wells to be drilled at The Geysers for various changes in the parameters that determine the number of megawatts on-line. The high replacement ratio (.112) of Curve 4 on Figure 8 was based on 5-acre well spacing. Present spacing is 20 acres; 5-acre spacing would only become a realistic alternative some time after the resource size is reached. However, the discussion in the previous paragraph shows that the low resource size which could eventually result in 5-acre spacing is unlikely. Figure 9 shows the number of wells forecasted for The Geysers using the time-dependent replacement ratio (20-acre spacing initially reducing to 10-acre). The assumptions of this time-dependent curve (Figure 9) are realistic and consistent with present strategy (20-acre spacing) and the argument that development in The Geysers will not be resource-size limited in the immediate future. The assumptions of Curve 4 of Figure 8 (5-acre

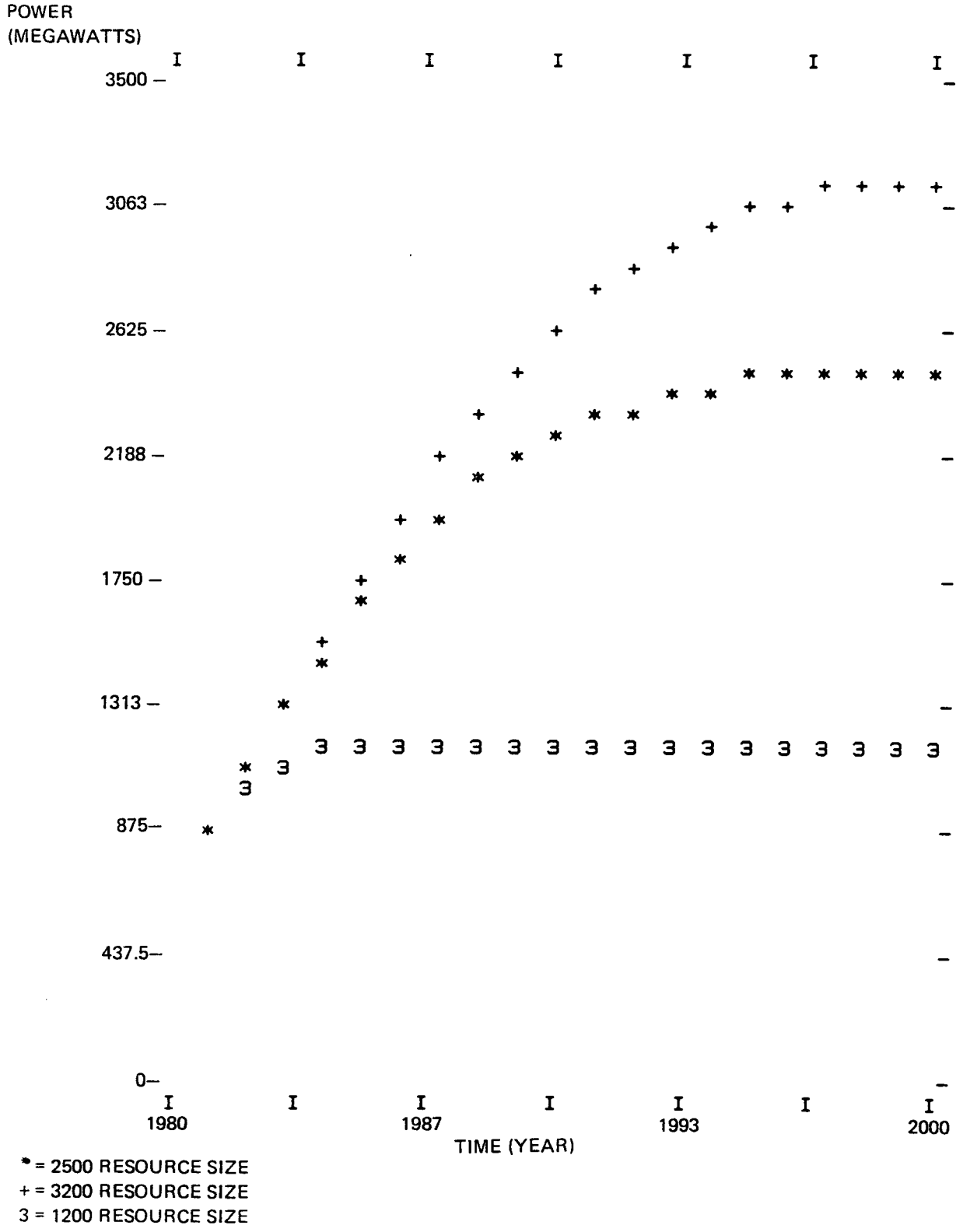


Figure 5. Power On-Line at the Geysers

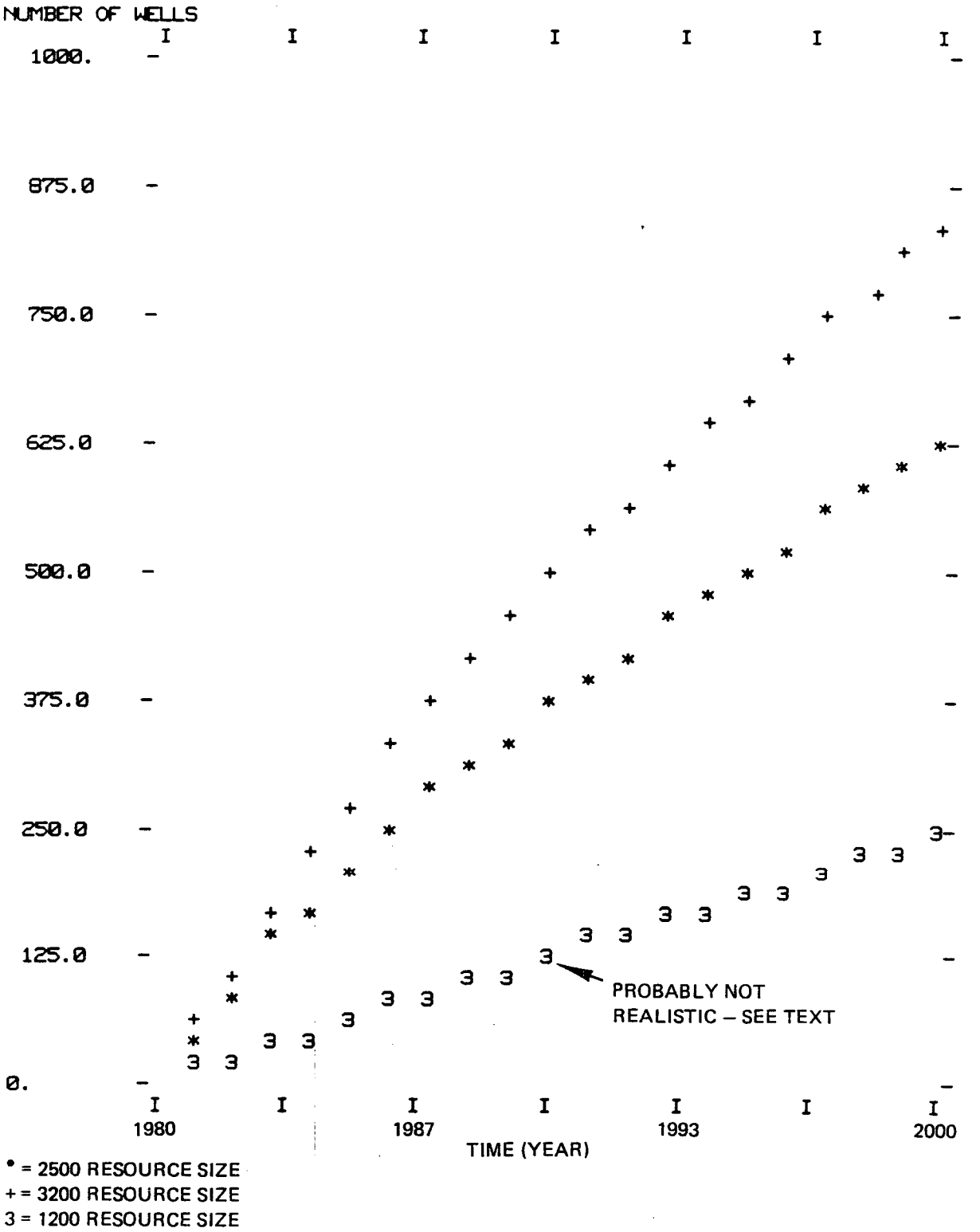


Figure 6. Number of Wells at the Geysers for Various Resource Sizes

BDM/A-81-763-TR

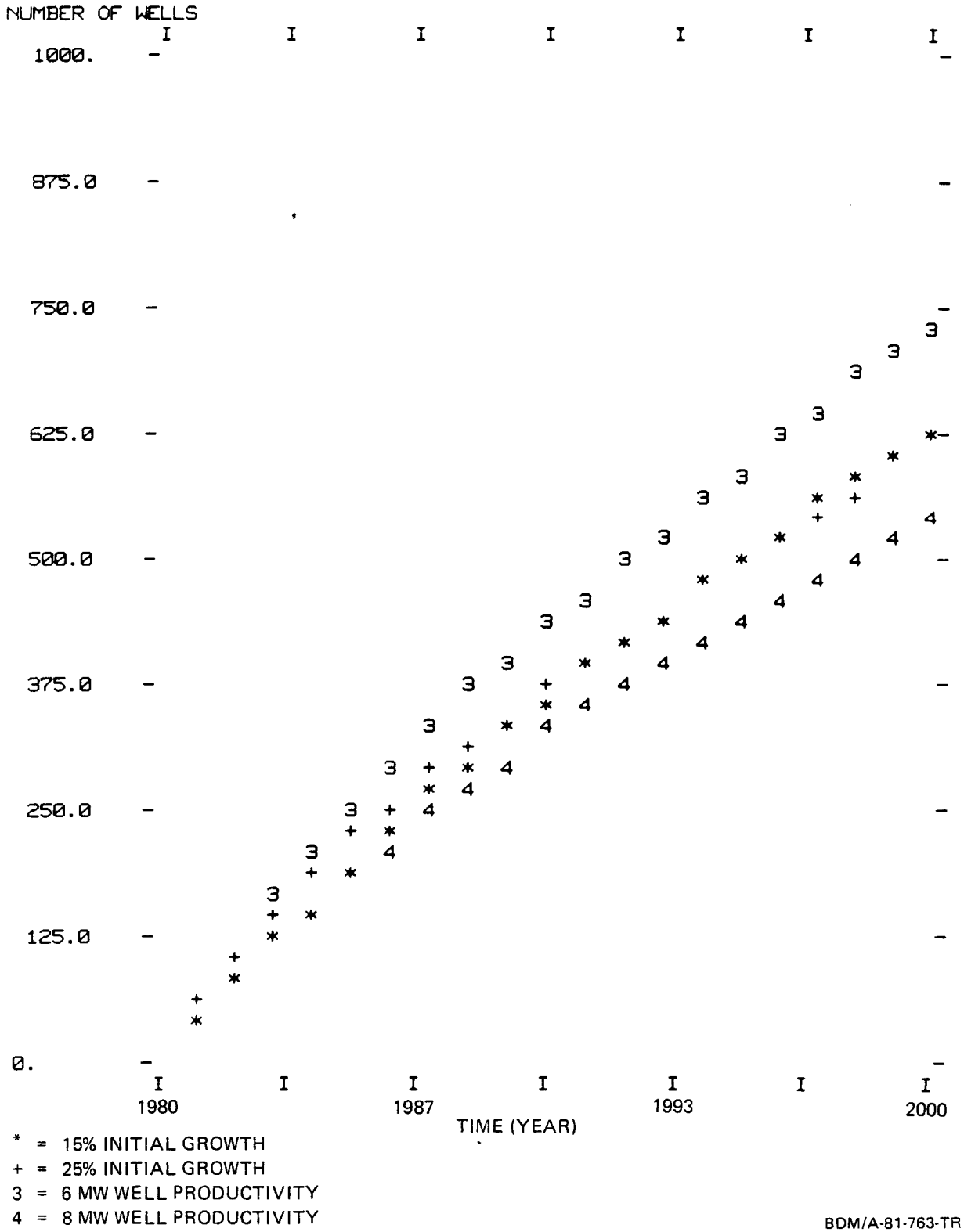
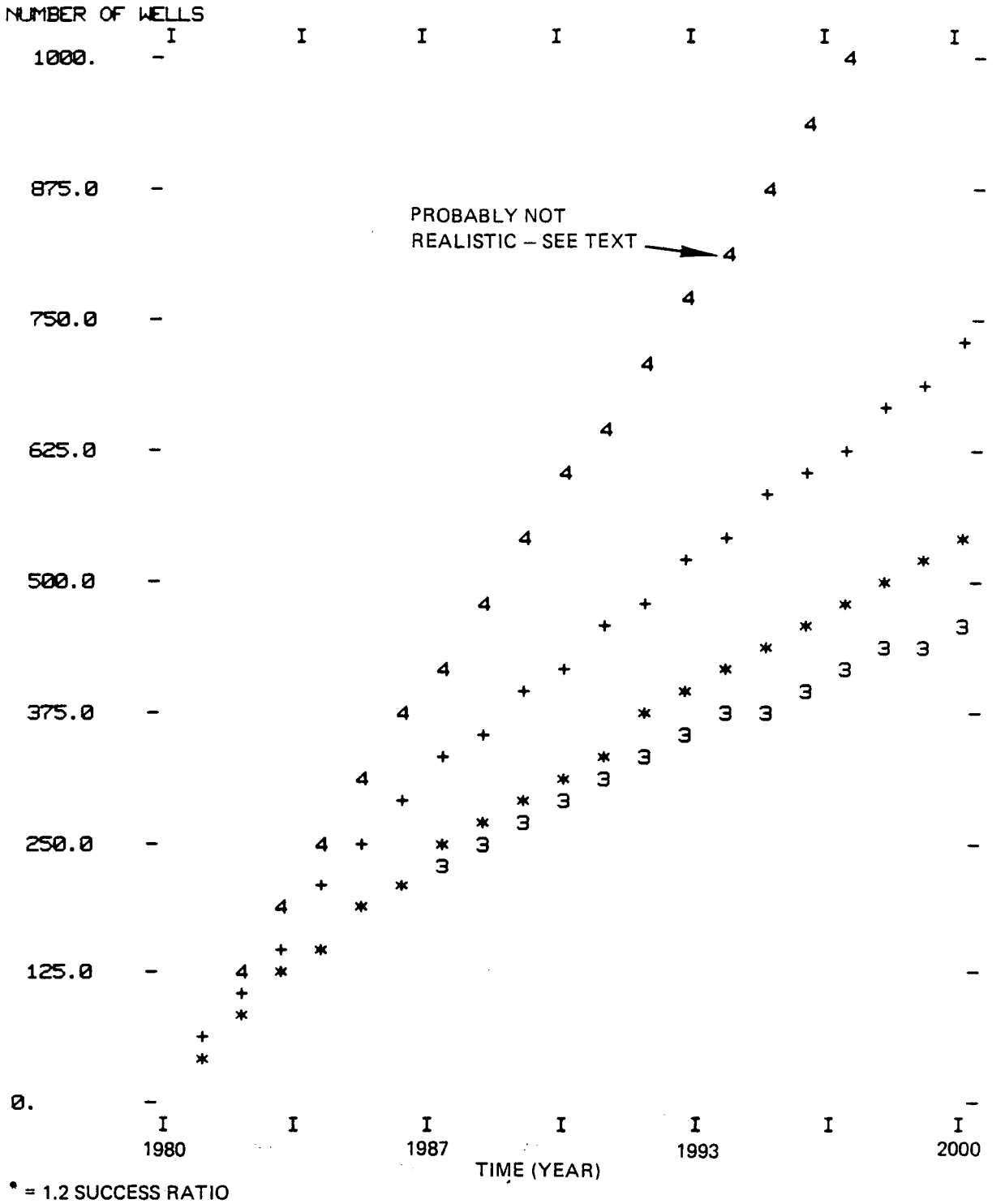


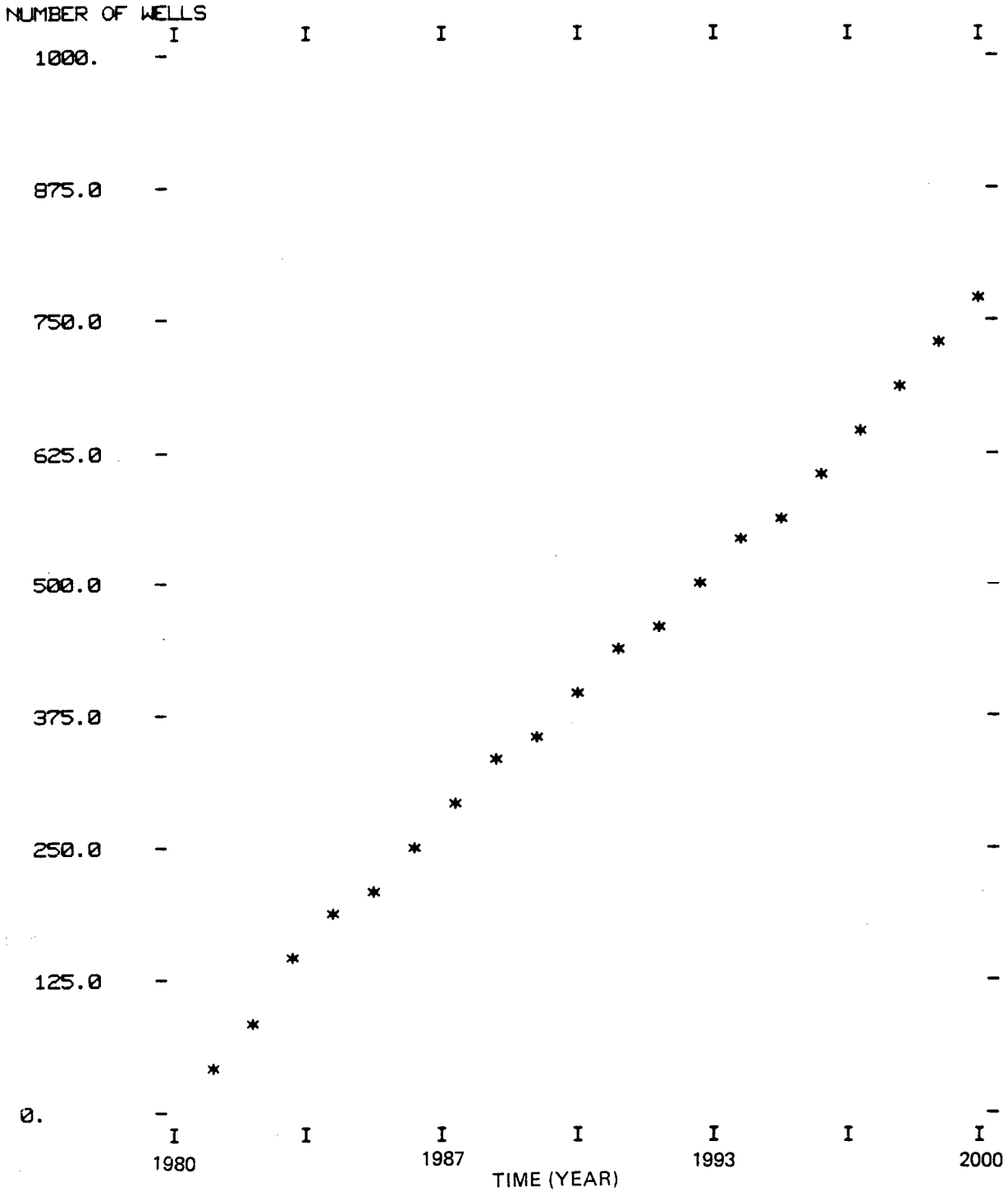
Figure 7. Number of Wells at the Geysers for Various Growth Percentages and Well Productivities



* = 1.2 SUCCESS RATIO
+ = 1.6 SUCCESS RATIO
3 = .03 REPLACEMENT RATIO
4 = .112 REPLACEMENT RATIO

BDM/A-81-763-TR

Figure 8. Number of Wells at the Geysers for Various Success and Replacement Ratios



BDM/A-81-763-TR

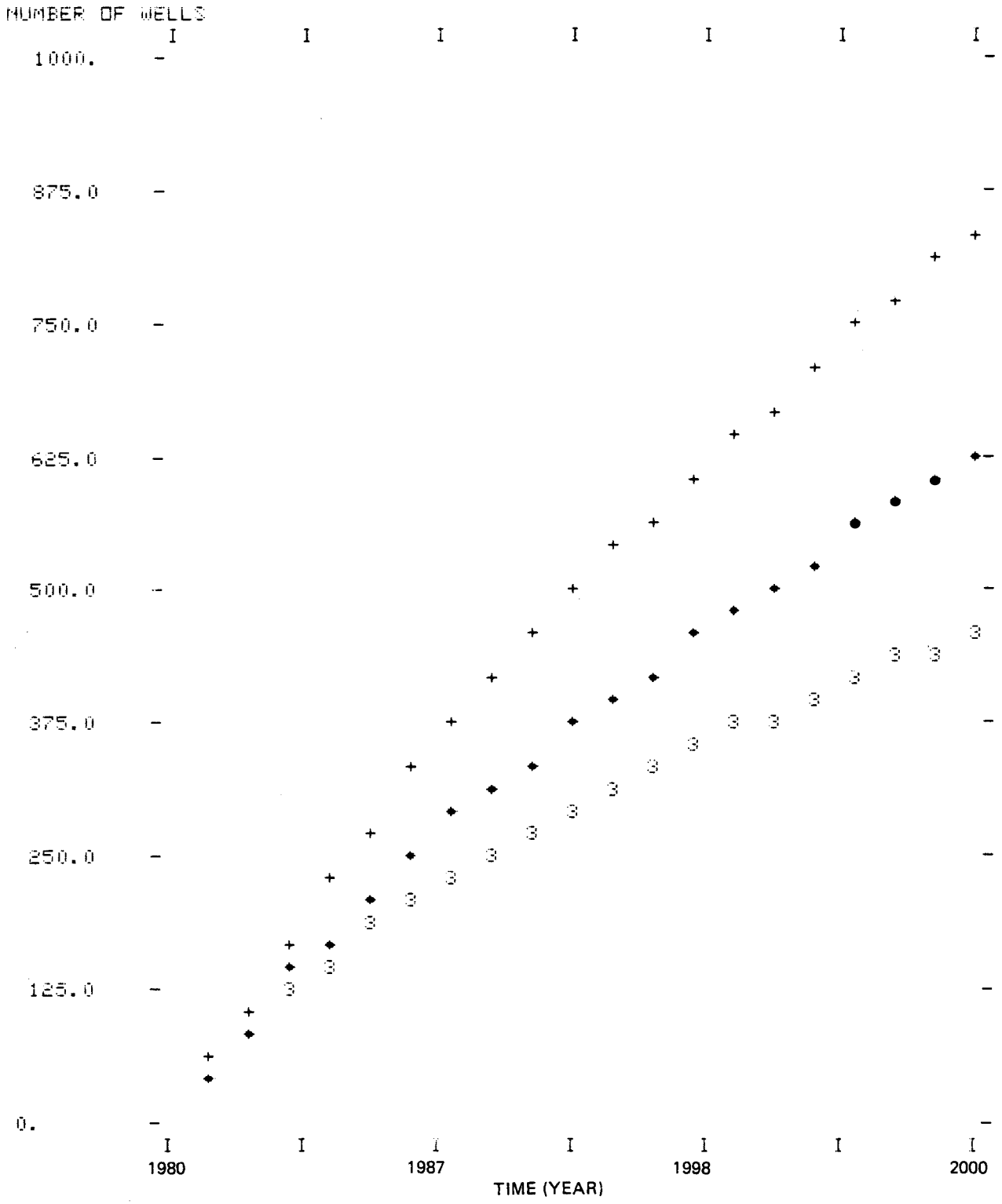
Figure 9. Time-Dependent Replacement Rate for the Geysers

spacing) are less realistic; therefore since Curve 4, Figure 8 is much farther off baseline than the curve of Figure 9 (time -dependent replacement), Curve 4, Figure 8 can be disregarded in favor of the curve on Figure 9.

Disallowing Curve 3, Figure 6 and Curve 4, Figure 8 (1200 MWe resource size and well replacement based on 5-acre spacing) two bounds on drilling activity at The Geyser appear reasonable. The largest forecast in the number of wells results from the possibility of the resource being 3200 MWe and the lowest forecast in the number of wells results from using .03 as the well replacement ratio (corresponding to 40-acre spacing). These forecasts are about 30 percent off the baseline case. Figure 10 shows the high, low, and baseline forecasts.

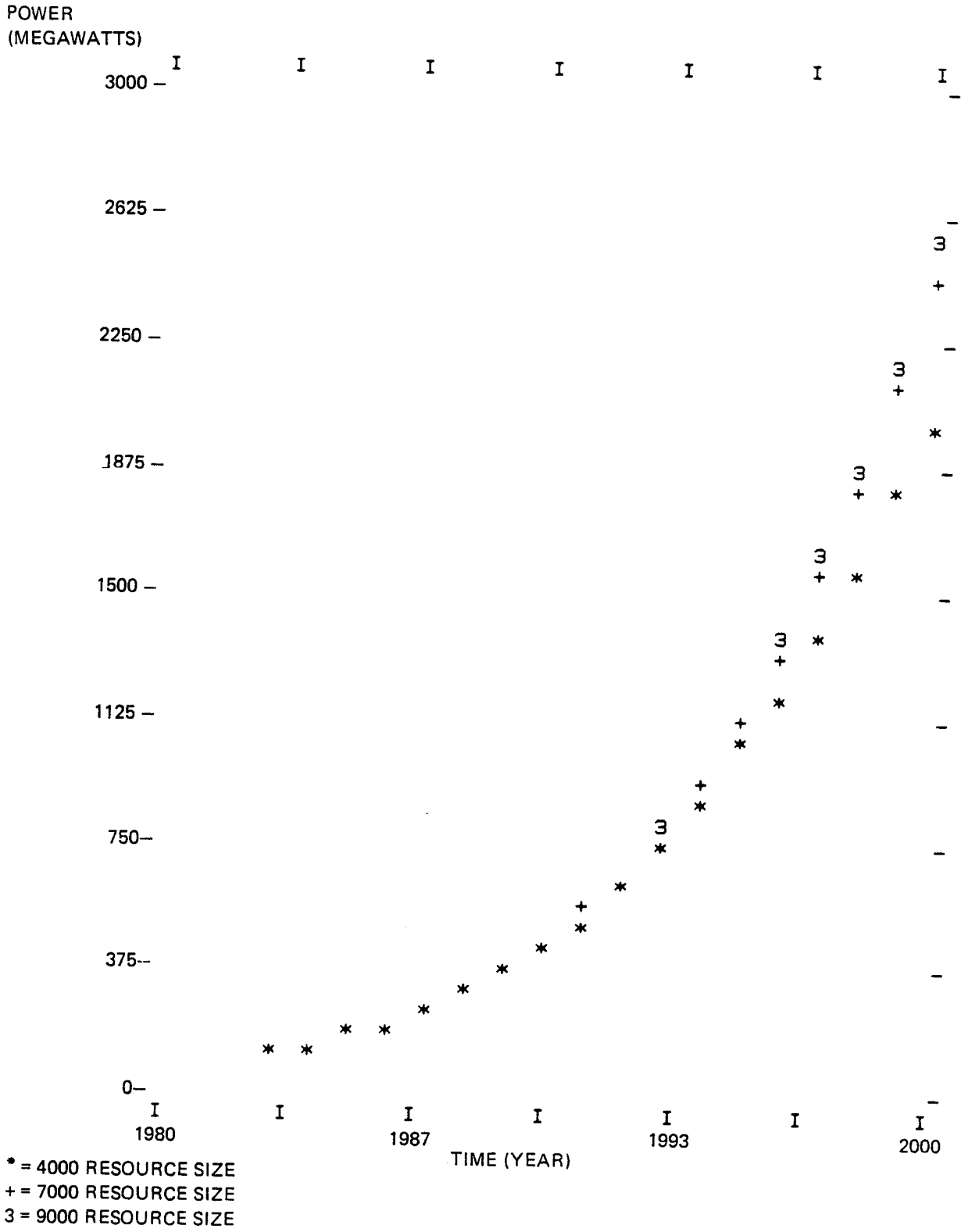
Imperial Valley--Figure 11 shows the forecasted megawatts on-line in the Imperial Valley as a function of resource size. If the resource is only 4000 MWe (Table 2), then the power on-line in 2000 A.D. will be 15 percent less than the baseline case. However, the discrepancy is only significant in the last 5-year period. Such a low value for the resource is not expected due to geologic conditions but may reflect unpredictable institutional barriers. If the resource is larger than presently expected (9000 MWe), then there would be a 4-percent increase in drilling over the expected baseline case. We can therefore see from Figure 11 that resource size is not critical in determining the number of wells that will be drilled in the Imperial Valley over the next 20 years.

Figure 12 shows how changing the start time for natural growth or changing the growth percentage will effect the number of wells drilled in the Imperial Valley. Start time moves the initial point on the figure affecting the number of wells drilled, but the effect is small compared to changing the growth percentage. Changing the growth percentage by 5 percent causes a 30-percent change in the number of wells drilled. Establishing the growth percentage and verifying that the growth will be exponential is difficult, to say the least. The only data are those of The Geysers and Cerro Prieto which may not be applicable. These data (Tables 5 and 6) indicate uncertainties of at least 5 percent. Thus, the



* = BASE CASE
\+ = LARGER RESOURCE SIZE
3 = LOW WELL REPLACEMENT RATE

Figure 10. High, Low, and Baseline Geysers Forecast



BDM/A-81-763-TR

Figure 11. Megawatts On-Line in the Imperial Valley as a Function of Resource Size

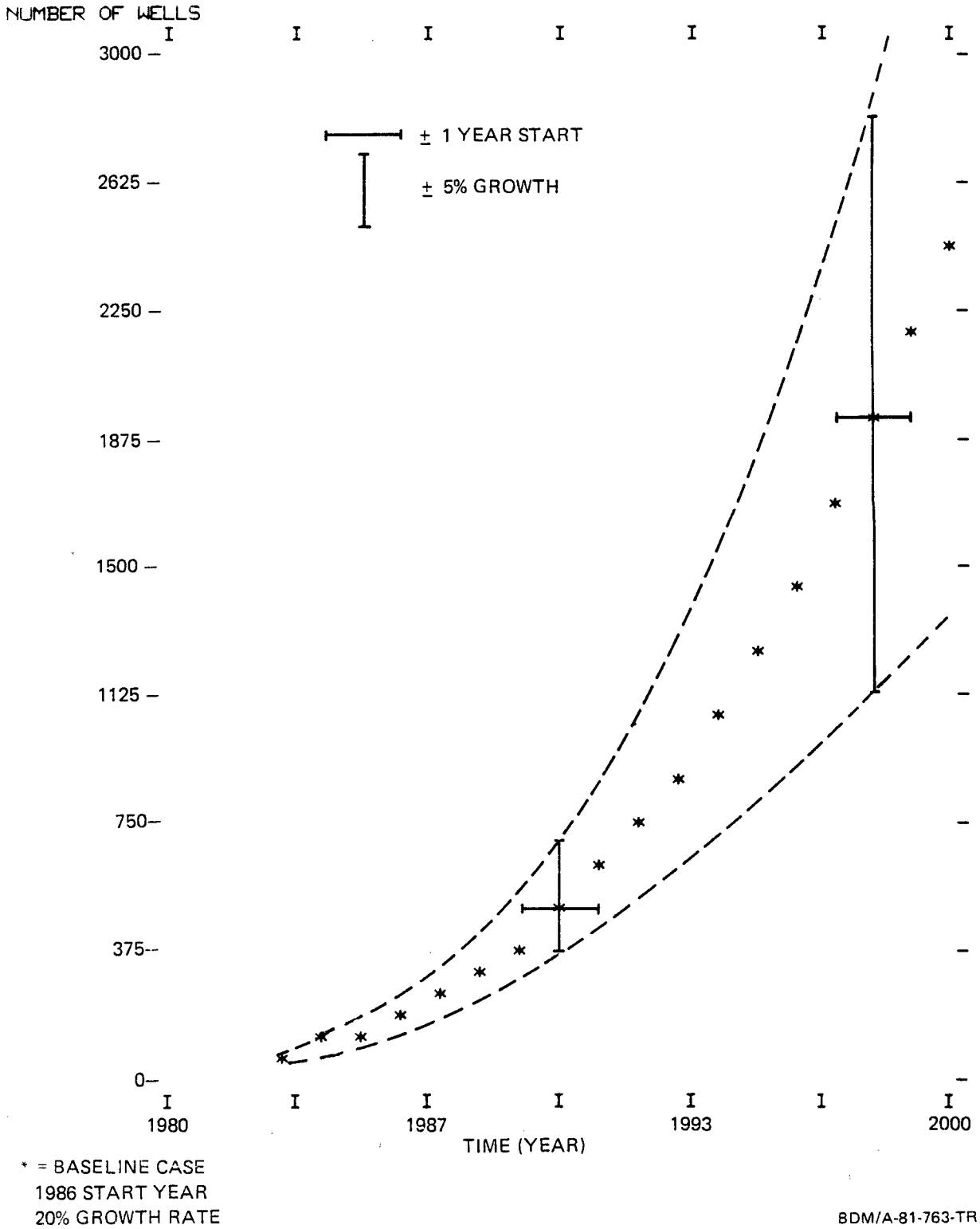


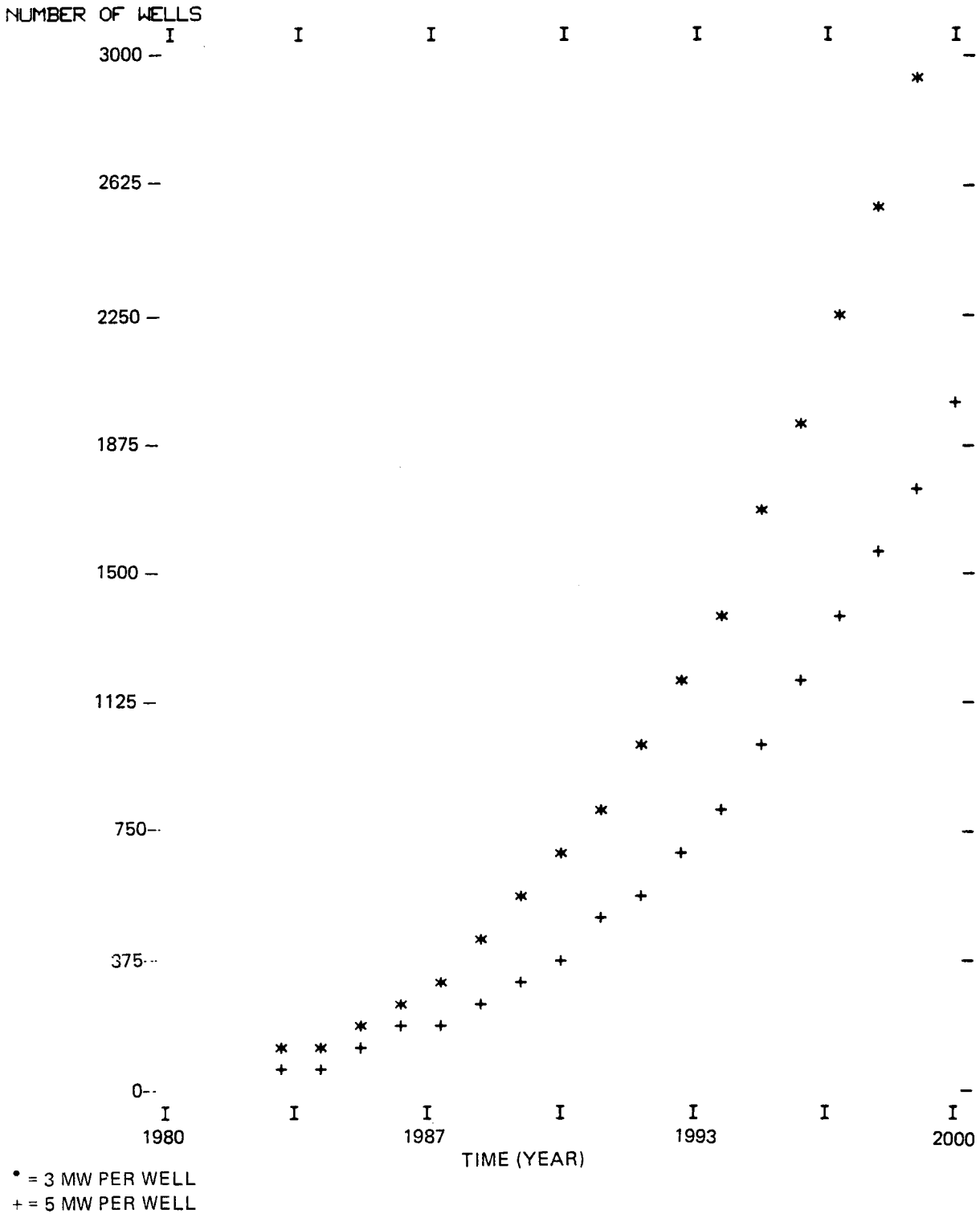
Figure 12. Effect of Changing Start Time and Growth Percentage on Wells Drilled in the Imperial Valley

uncertainty defined by the vertical bar on Figure 12 is very real, and may possibly be construed as the minimum uncertainty.

Figure 13 shows the number of wells forecasted to be drilled in the Imperial Valley as a function of the power output (equivalent MWe) of the wells. Comparing to Figure 12, we see that uncertainty in the power output is not as significant as uncertainty in the growth percentage. Figure 14 shows the number of wells forecasted to be drilled in the Imperial Valley as a function of the drilling success ratio and the well replacement rate. Again, the effects of uncertainties in these parameters is much less than the effect of uncertainty in growth percentage.

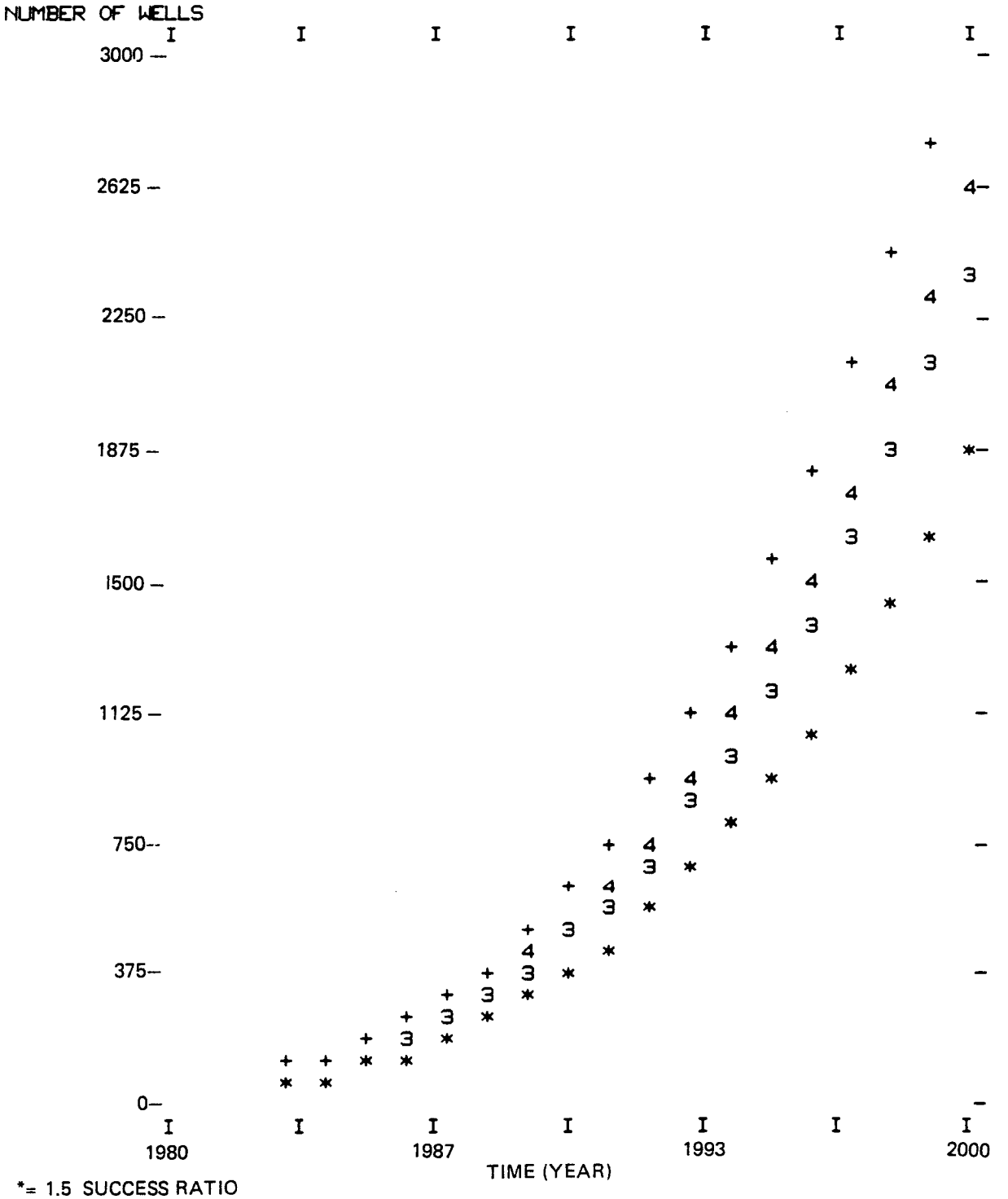
The largest uncertainty in the number of wells forecasted to be drilled in the Imperial Valley results from uncertainty in the growth rate. Figure 15 shows the baseline case together with the high and low forecast.

One of the basic conclusions of this study is the dominance of drilling activity in the Imperial Valley. Comparing Figures 6 and 12, we see that even with the low growth percentage for the Imperial Valley and the maximum resource size for The Geysers, almost twice as many wells will be drilled in the Imperial Valley as The Geysers. If we take parameter values in Table 2 which reduce the number of wells, then the number of wells drilled in the Imperial Valley will be the same as the baseline forecast for The Geysers. Such a possibility is unlikely.



BDM/A-81-763-TR

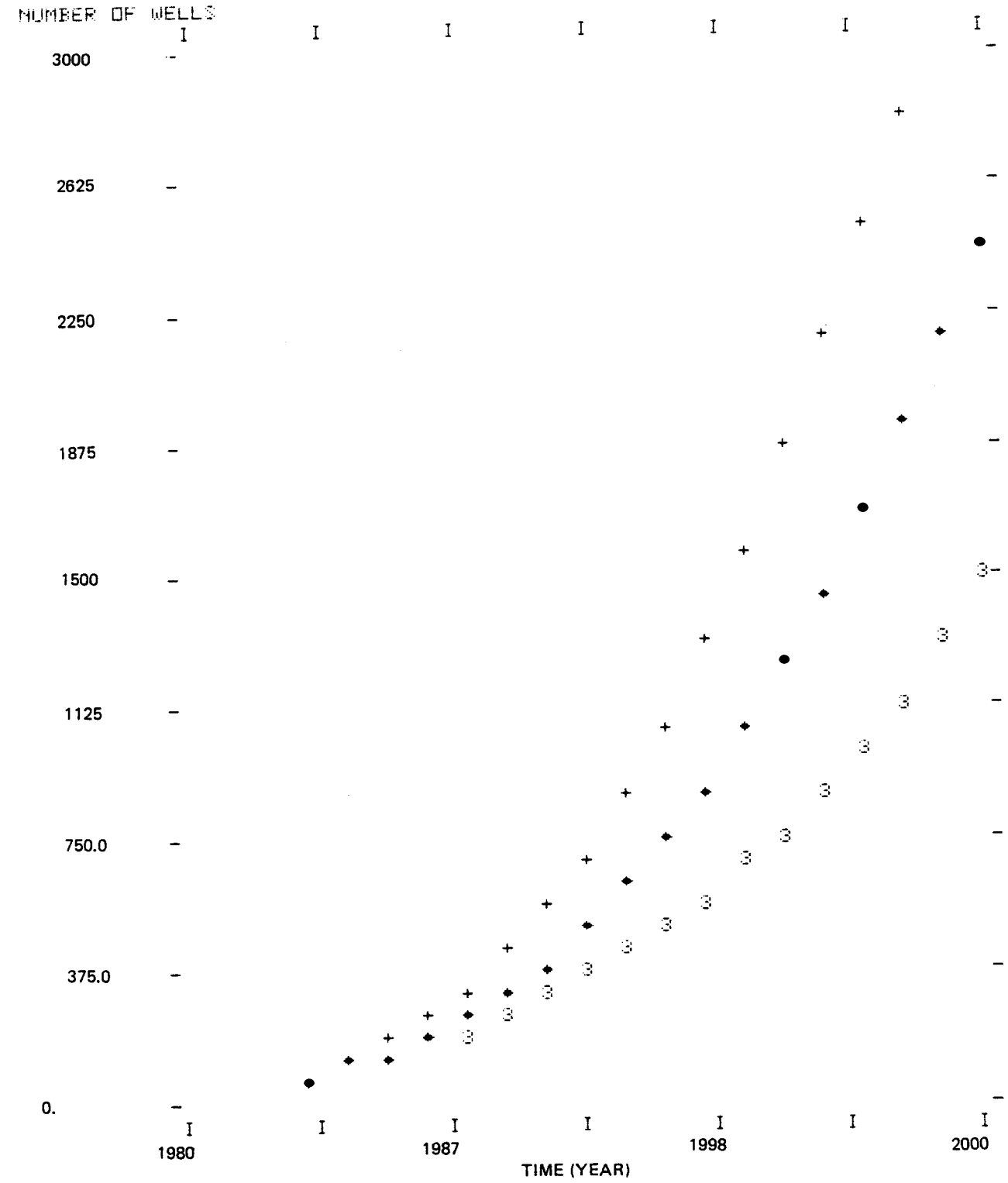
Figure 13. Number of Wells Drilled in the Imperial Valley as a Function of the Power Output of the Wells



*= 1.5 SUCCESS RATIO
+= 2.5 SUCCESS RATIO
3= .057 REPLACEMENT RATE
4= .086 REPLACEMENT RATE

BDM/A-81-763-TR

Figure 14. Effect of Success Ratio and Replacement Rate on Wells Drilled in the Imperial Valley



* = BASE CASE
\+ = HIGH GROWTH RATE
3 = LOW GROWTH RATE

Figure 15. High, Low, and Baseline Imperial Valley Forecast

APPENDIX A
Computer Code

Computer Code

Introduction

GEODRL was developed specifically for forecasting geothermal well drilling activity from the present to the year 2000. The program estimates the number of (1) new wells, (2) new non-producing wells, (3) replacement wells, and (4) total wells for each year, and subtotals for every 5 years. The computations for this forecast are based on historical drilling data in the reservoir being evaluated, and on the reservoirs generating capacity.

Program GEODRL is an interactive program written for the Sandia National Laboratories of Albuquerque (SNLA) Network Operating System (NOS) Control Data Corporation (CDC) 6600 computer. GEODRL prints out the forecasting data in tabular form and has an optional plotting capability. GEODRL may be copied from the listing provided and run at other installations since it is written in ANSI FORTRAN.

In order for a user to access GEODRL on NOS, the user must be familiar with how to acquire an account and log into NOS. These instructions are found in the NOS NEWS NOTES,[20] a document that describes SNLA NOS. If the user wishes to make changes to GEODRL, then a second manual may be needed depending on the user's familiarity with FORTRAN 5. This manual is the CDC FORTRAN VERSION 5 REFERENCE MANUAL.[21]

Program GEODRL is an interactive program made up of a main program, two functions, and four subroutines. Figure A-1 illustrates the linkage structure of these routines. Program GEODRL begins execution with subroutine INIT to initialize all variables then calls the input processor INPRO to read in the input values from the users. INPRO prompts the user for all the input parameters. Figure A-2 illustrates how the user interacts with GEODRL. After the input parameters have been defined, GEODRL computes the production and the various number of wells using functions CMPC and CUBIC. At the same time, these computed values are printed out in tabular form as illustrated in Figure A-2. When the program has completed the tables, subroutine PLOT is called if the user has requested more than zero curves to be plotted. If more than one curve is to be

plotted on the graphs, GEODRL loops back through INPRO and through the table generation until all the curves have been generated before entering PLOT. In PLOT the user is asked for plot limits on two types of graphs. These graphs are production versus years and number of wells versus years. After completing the plots GEODRL reenters INPRO and asks for changes to all parameters. Reentering INPRO closes the loop which is continued until the user types in a carriage (CR) return in column one. This column one (CR) tells GEODRL that the input information is complete and so execution is terminated. This may be done at any point in the program when the user is prompted with a question mark(?). In the illustrated run in Figure A-2 all the user-supplied commands are shown with underlines.

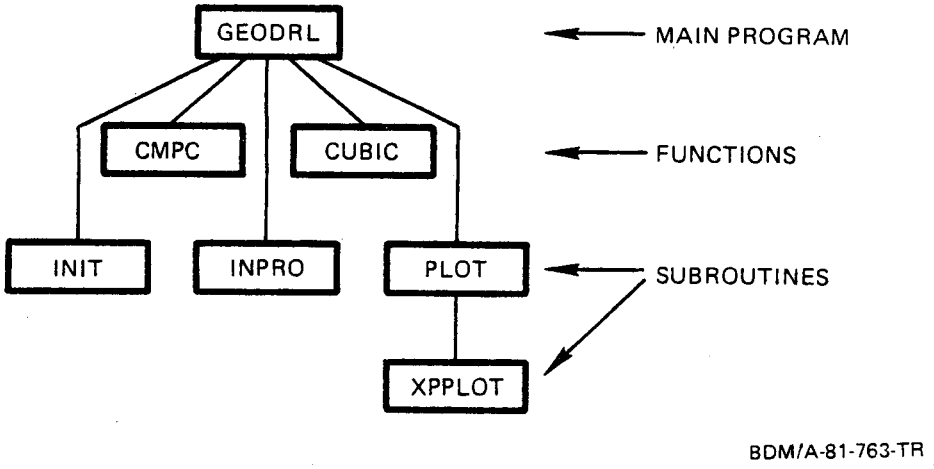


Figure A-1. GEODRL Routine Linkage Structure

```
/BATCH
$RFL,0.
/GET,GEODRL5
/FTN5(I=GEODRL5,L=FTNNLST,GO)

     G E O D R L 5   R U N

  GEODRL COMPUTES PRODUCTION AND NUMBER OF WELLS DRILLED
  BETWEEN START YEAR AND THE YEAR 2000 BASED ON THE
  FOLLOWING PARAMETER VALUES. YOU MAY CHANGE ANY VALUE
  BY ENTERING A NEW VALUE WHEN GEODRL PROMPTS YOU WITH A
  <?>. IF YOU DO NOT WISH TO CHANGE A VALUE ENTER A COMMA
  FOLLOWED BY A <CR>. IF YOU WISH TO TERMINATE THE RUN
  ENTER A <CR> RIGHT AFTER THE <?>.


 BEGIN ENTERING NEW VALUES FOR CASE 1

  1;MAXIMUM POTENTIAL PRODUCTION OF RESERVOIR=7000.(MEGAWATTS)
? ,
  2;FIRST YEAR ON-LINE PRODUCTION=200(MEGAWATTS)
? ,
  3;YEAR GROWTH STARTS=1986
? 1987
  4;NUMBER OF YEARS NEW WELLS MUST BE DRILLED BEFORE
  PLANT IS COMMISSIONED=3
? ,
  5;NUMBER OF YEARS REPLACMENT WELLS MUST BE DRILLED BEFORE NEEDED=
 1
? ,
  THREE SETS OF COEFICENTS FOR CUBIC FITS FOLLOW:
  ENTER NEW COEFICIENTS IN THE ORDER THEY APPEAR IN THE
  EQUATIONS (SEPARATE VALUES WITH COMMAS)
   T=TIME SINCE GROWTH STARTS(YEARS)
  6;WELL PRODUCTION=(4.)+(0.)*T+(0.)*T**2+(0.)*T**3
? ,,,,
  7;(NEW WELLS)/(SUCCESSFUL WELLS)=(2.)+(0.)*T+(0.)*T**2+(
 0.)*T**3
? ,,,,
  8;REPLACMENT RATE=(.044)+(0.)*T+(0.)*T**2+(0.)*T**3
? ,,,,
  9;INITIAL PERCENTAGE GROWTH RATE=.2
? ,
 10;INITIAL NUMBER OF WELLS FACTOR=.5
? ,
 11;NUMBER OF CURVES ON ONE SET OF GRAPHS=0
? 1

  DO YOU WISH TO REENTER ANY VALUES(NO/YES)
? NO
```

BDM/A-81-763-TR

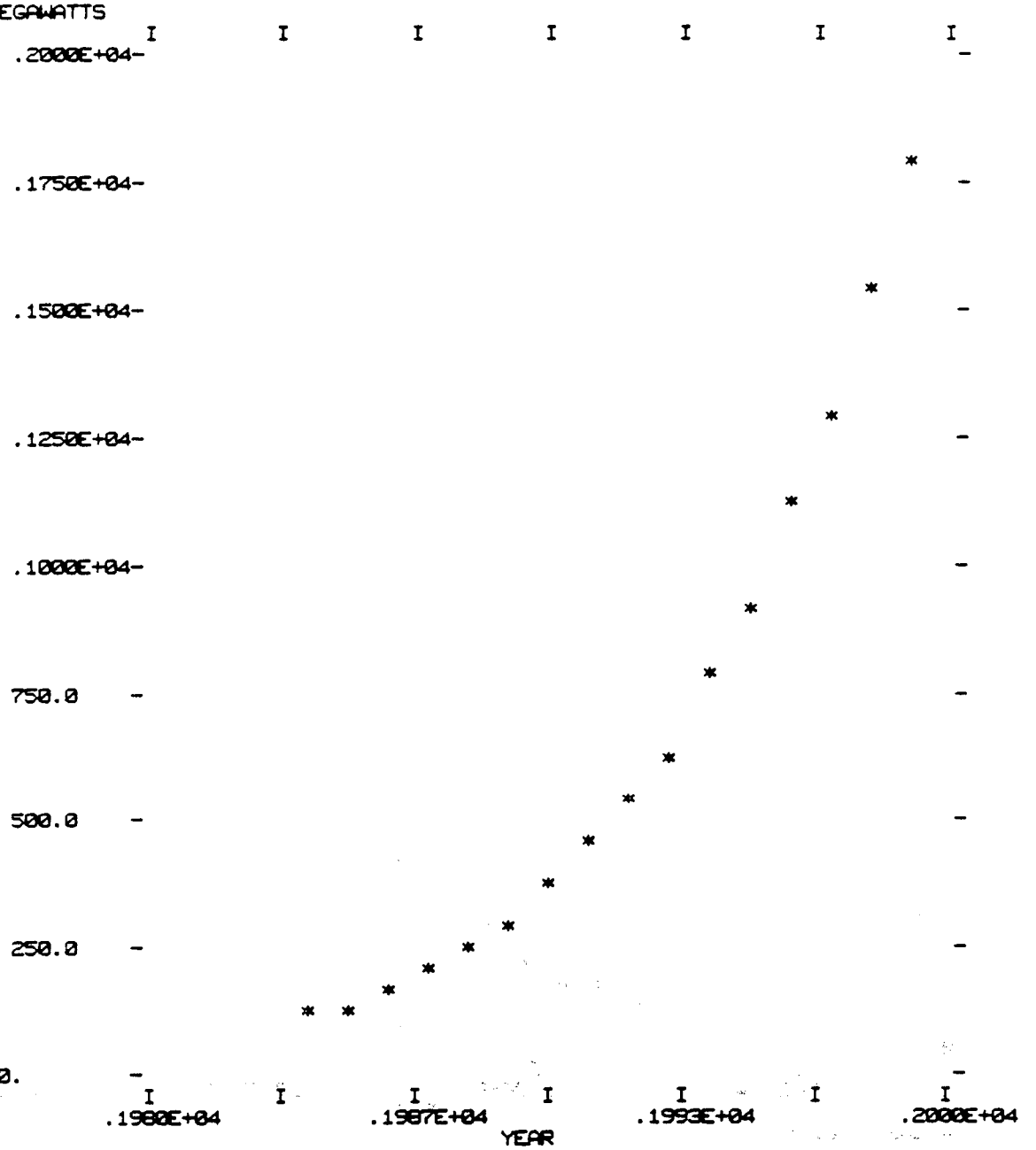
Figure A-2. GEODRL Run

YEAR	PROD(MEGW)	NEW	BAD	REPLACE	TOTAL	SUM
INITIAL		50.			50.	50.
1984		11.	11.	3.	25.	75.
1985		13.	13.	4.	30.	105.
5 YEAR TOTAL		74.	24.	7.	105.	
1986		16.	16.	4.	37.	142.
1987	200.	19.	19.	5.	44.	186.
1988	244.	23.	23.	7.	53.	239.
1989	298.	28.	28.	8.	63.	302.
1990	362.	33.	33.	10.	75.	377.
5 YEAR TOTAL		119.	119.	34.	272.	
1991	440.	38.	38.	12.	88.	466.
1992	533.	45.	45.	14.	103.	569.
1993	643.	51.	51.	17.	120.	689.
1994	774.	58.	58.	20.	137.	826.
1995	927.	66.	66.	24.	155.	982.
5 YEAR TOTAL		258.	258.	88.	604.	
1996	1106.	72.	72.	29.	174.	1155.
1997	1311.	79.	79.	34.	191.	1346.
1998	1545.	84.	84.	40.	207.	1553.
1999	1807.	88.	88.	46.	221.	1775.
2000	2096.	90.	90.	53.	232.	2007.
5 YEAR TOTAL		412.	412.	202.	1025.	

BDM/A-81-7[illegible]3-TR

Figure A-2. GEODRL Run (Continued)

```
MAXIMUM PRODUCTION VALUE FOR PLOT=3000.(MEGAWATTS)
? 2000
PRODUCTION
MEGAWATTS
```




```
*=CASE NUMBER  1

IS PLOT OK
? YES
```

BDM/A-81-763-TR

Figure A-2. GEODRL Run (Continued)

```
MAXIMUM NUMBER OF WELLS VALUE FOR PLOT=3000.(WELLS)
? 2000
NUMBER OF WELLS
          I         I         I         I         I         I         I
  .2000E+04-                                                          *-
                                                                  *
  .1750E+04-                                                          -
                                                              *
  .1500E+04-                                                          -
                                                          *
  .1250E+04-                                                          -
                                                      *
  .1000E+04-                                                  *       -
                                                          *
  750.0    -                                                          -
                                                      *
                                                  *
  500.0    -                                                          -
                                              *
                                          *
                                      *
  250.0    -                          *                               -
                                  *
                              * *
                          *
  0.       -                                                          -
          I         I         I         I         I         I         I
        .1980E+04           .1987E+04           .1993E+04           .2000E+04
                                     YEAR
  *=CASE NUMBER  1

  IS PLOT OK
? YES
```

BDM/A-81-763-TR

Figure A-2. GEODRL Run (Continued)

```
BEGIN ENTERING NEW VALUES FOR CASE 2
 1;MAXIMUM POTENTIAL PRODUCTION OF RESERVOIR=7000.(MEGAWATTS)
? 2
    1.661 CP SECONDS EXECUTION TIME.
/
```

BDM/A-81-763-TR

Figure A-2. GEODRL Run (Concluded)

Procedures for Use on the SNLA NOS Computer

The procedure for running GEODRL is illustrated with lower case letter commands in the sample run listing Figure A-2. The batch, get, and ftn5 commands are used right after the user has logged into NOS. This will begin execution of GEODRL as illustrated. If after terminating a GEODRL run, the user wishes to make another run then the command lgo is typed. This will work only when the lgo file from the illustrated ftn5 command is still a local file and the user has not signed off or logged off since the last execution of GEODRL. If the user wishes to make changes to the source code of GEODRL, it can be done using the NOS editor. A listing of the program is found in Figure A-3.

If, when GEODRL is being executed a fatal error occurs and the user cannot determine the problem from the listing, then do the following: 1) rewind all files with the command "ra", and 2) then execute the ftn5 command by adding the parameter "dp=pmd" (post mortem dump). This will allow the user the opportunity to recreate the error condition in order to generate more detailed information.

```
      PROGRAM GEODRL(INPUT,OUTPUT)
C THIS PROGRAM COMPUTES THE NUMBER OF WELLS WHICH CAN BE DRILLED
C AND THE TOTAL PRODUCTION CAPACITY BY THE YEAR 2000
C
C VARIABLES      DEFINITION
C *COEFRR(5)     REPLACEMENT AND ANNUAL RATE COEFICIENTS  AS A
C                 FUNCTION OF TIME. ENTRIES 1 TO 4 ARE COEFICIENTS AS
C                 ILLUSTRATED IN FUNCTION CUBIC. ENTRY 5 IS THE COMPUTATIONAL
C                 RESULT OF THE 4 COEFICIENTS
C *COEFTN(5)     COEFICIENTS USED TO COMPUTE THE RATIO OF NEW WELLS
C                 DRILLED TO SUCCESSFUL PRODUCING WELLS, SAME FORM AS COEFRR
C *COEFWP(5)     CUBIC FIT COEFICIENTS FOR WELL PRODUCTION, SAME FORM AS COEFRR
C  DRILW(30)     OUTPUT TABLE OF TOTAL NUMBER OF WELLS
C  EEGR          EFFECTIVE EXPONETIAL GROWTH RATE
C *GRWRAT        INITIAL PERCENTAGE GROWTH RATE
C  IEOF          END OF INPUT FLAG
C  IOTA          INDEX FOR OUTPUT TABLE ARRAYS
C  IYEAR         LOOP INDEX IN YEARS FROM YEAR CALCULATION STARTS TO 2000
C  IYRCAL        YEAR CALCULATIONS START(BEFORE MEGAWATTS GO ON-LINE
C                 BECAUSE WELLS MUST BE DRILLED IN ADVANCE)
C *IYRGRW        YEAR GROWTH STARTS
C *IYRON         MEGAWATTS ON-LINE FIRST YEAR
C  NOLAY         COUNTER FOR THE NUMBER OF OVERLAYS TO BE PLOTTED
C *NPLOT         NUMBER OF OVERLAY PLOTS TO BE MADE ON EACH PLOT
C  NPTS(4)       NUMBER OF POINTS TO BE PLOTTED FOR ONE CURVE
C                 UP TO 4 CURVES MAY BE PLOTTED
C *NYCOM         NUMBER OF YEARS NEW WELLS MUST BE DRILLED BEFORE
C                PLANT IS COMISSIONED
C *NYRW          NUMBER OF YEARS REPLACMENT WELLS MUST BE DRILLED BEFORE NEEDED
C  PRODMG(30)    OUTPUT TABLE FOR MEGAWATTS ON-LINE
C *PRODMX        MAXIMUM VALUE OF THE Y AXIS FOR THE PRODUCTION PLOT
C  PWNEW(30)     OUTPUT TABLE FOR NUMBER OF NEW PRODUCTION WELLS
C  PWNEW5        5 YEAR TOTAL OF NEW PRODUCTION WELLS
C  PWNON(30)     OUTPUT TABLE OF NEW NON-PRODUCING WELLS
C  PWNON5        5 YEAR TOTAL OF NEW NON-PRODUCING WELLS
C  RANGE(5)      X AND Y LIMITS FOR PLOTS
C  REPWEL(30)    OUTPUT TABLE FOR NUMBER OF REPLACMENT WELLS
C *RESPOT        MAXIMUM RESERVOIR POTENTIAL (MEGAWATTS)
C *RIWF          INITIAL WELL FACTOR
C  RPWEL5        5 YEAR TOTAL OF REPLACMENT WELLS
C  TIME          YEAR COUNTER
C  TOTWEL        TOTAL NUMBER OF WELLS FOR EACH YEAR
C  TOTWL5        TOTAL OF WELLS FOR FIVE YEARS
C  TOTWYR(30)    OUTPUT TABLE FOR TOTAL NUMBER OF WELLS
C  TPROD(30,4)   Y VALUES FOR TOTAL PRODUCTION PLOT
C  TWELLS(30,4)  Y VALUES FOR TOTAL NUMBER OF WELLS PLOT
C *WELLMX        MAXIMUM X VALUE ON PLOTS
C  YEARS(30,4)   X VALUES FOR THE PLOTS
C
C *NOTE: THESE ARE USER INPUT PARAMETERS
C
C
```

BDM/A-81-763-TR

Figure A-3. GEODRL Computer LISTIN

```
      DIMENSION PRODMG(30),PWNEW(30),PWNON(30),REPWEL(30),TOTWYR(30),
     1YEARS(30,4),TPROD(30,4),TWELLS(30,4),RANGE(5),NPTS(4),COEFRR(5),
     $ COEFTN(5),DRILW(30),COEFWP(5), ICP(4)
      LOGICAL FIRST
C     INITIALIZE PARAMETERS
      CALL INIT(COEFRR,COEFTN,COEFWP,GRWRAT,IEOF,IYRGRW,IYRON,NOLAY,
     A NPLOT,NYCOM,NYRW,RESPOT,RIWF)
C    *LOOP THROUGH CASES WHICH USER CONTINUES TO SELECT
 1000 CONTINUE
C      *READ INPUT
       CALL INPRO(RESPOT,IYRON,IYRGRW,NYCOM,NYRW,COEFWP,COEFTN,
     $  COEFRR,GRWRAT,NPLOT,RIWF,IEOF,NOLAY,ICP)
C      *CHECK FOR END OF INPUT
       IF(IEOF.EQ.1)GO TO 10000
C       *LIMIT NUMBER OF PLOT OVERLAYS TO 4
        IF(NPLOT .GT. 4)THEN
          NPLOT=4
        END IF
        IOTA=0
        PRINT*,' '
        PRINT*,' '
        PRINT*,'YEAR    PROD(MEGW)     NEW        BAD       REPLACE',
     A    '     TOTAL     SUM'
C      *COMPUTE GROWTH RATE CORRECTION
        EEGR = GRWRAT*RESPOT/(RESPOT-FLOAT(IYRON))
C      *INITIALIZE PARAMETERS
        TOTWEL=0
        PWNEW5 = 0.
        PWNON5 = 0.
        RPWEL5 = 0.
        TOTWL5 = 0.
C      *INCREMENT OVERLAY PLOT COUNTER
        NOLAY = NOLAY + 1
C      *SET START TIME FOR LOOP
        IYRCAL = IYRGRW-NYCOM
        FIRST = .TRUE.
C      *LOOP FROM IYRCAL TO THE YEAR 2000
        DO 4000 IYEAR=IYRCAL,2000
C        *CHECK FOR YEARS BEFORE PRESENT YEAR
         IF(IYEAR .GE. 1981)THEN
           IOTA=IOTA+1
C         *COMPUTE GENERATION CAPACITY AND NUMBER OF WELLS FOR EACH YEAR
          PRODMG(IOTA)=CMPC(IYEAR,IYRGRW,EEGR,RESPOT,IYRON)
          TIME = FLOAT(IYEAR - IYRGRW)
          COEFWP(5) = CUBIC(COEFWP,TIME)
          COEFTN(5) = CUBIC(COEFTN,TIME)
          COEFRR(5) = CUBIC(COEFRR,TIME)
          PWNEW(IOTA)=(CMPC(IYEAR+NYCOM+1,IYRGRW,EEGR,RESPOT,IYRON)-
     A     CMPC(IYEAR+NYCOM,IYRGRW,EEGR,RESPOT,IYRON))/COEFWP(5)
          PWNON(IOTA)=(COEFTN(5)-1)*PWNEW(IOTA)
          REPWEL(IOTA)=COEFTN(5)*COEFRR(5)*CMPC(IYEAR+NYRW,IYRGRW,
     A     EEGR,RESPOT,IYRON)/COEFWP(5)
```

BDM/A-81-763-TR

Figure A-3. GEODRL Computer LISTIN (Continued)

```
                TOTWYR(IOTA)=PWNEW(IOTA)+PWNON(IOTA)+REPWEL(IOTA)
C              *CHECK FOR FIRST YEAR
                IF(IYRGRW .GT. 1981  .AND. FIRST)THEN
C                *COMPUTE INITIAL NUMBER OF WELLS
                 FIRST = .FALSE.
                 TOTWEL = RIWF*COEFTN(5)*FLOAT(IYRON)/COEFWP(5)
                 PWNEW5 = PWNEW5 + TOTWEL
                 TOTWL5 = TOTWL5 + TOTWEL
C                *PRINT RESULTS
                 PRINT 9000,TOTWEL,TOTWEL,TOTWEL
                END IF
                TOTWEL=TOTWEL+TOTWYR(IOTA)
                DRILW(IOTA)=TOTWEL
C              *PRINT RESULTS
                IF(IYEAR .LT. IYRGRW)THEN
C                *PRINT RESULTS BEFORE PRODUCTION
                 PRINT 9100,IYEAR,PWNEW(IOTA),PWNON(IOTA),REPWEL(IOTA),
     A             TOTWYR(IOTA),DRILW(IOTA)
                ELSE
C                *PRINT RESULTS AFTER PRODUCTION
                 PRINT 9200,IYEAR,PRODMG(IOTA),PWNEW(IOTA),PWNON(IOTA),
     A             REPWEL(IOTA),TOTWYR(IOTA),DRILW(IOTA)
                END IF
C              *SUM FIVE YEAR TOTALS
                PWNEW5 = PWNEW5 + PWNEW(IOTA)
                PWNON5 = PWNON5 + PWNON(IOTA)
                RPWEL5 = RPWEL5 + REPWEL(IOTA)
                TOTWL5 = TOTWL5 + TOTWYR(IOTA)
C              *SAVE PLOTTING INFORMATION
                YEARS(IOTA,NOLAY) = FLOAT(IYEAR)
                NPTS(NOLAY) = IOTA
                TPROD(IOTA,NOLAY)=PRODMG(IOTA)
                TWELLS(IOTA,NOLAY)=DRILW(IOTA)
C              *PRINT FIVE YEAR TOTAL EVERY FIVE YEARS
                IF(MOD(IYEAR,5).EQ.0)THEN
                 PRINT 3000,PWNEW5,PWNON5,RPWEL5,TOTWL5
 3000            FORMAT(15X,4(5X,5H-----),/,15H  5 YEAR TOTAL ,4F10.0,/)
                 PWNEW5 = 0.
                 PWNON5 = 0.
                 RPWEL5 = 0.
                 TOTWL5 = 0.
                END IF
              END IF
 4000       CONTINUE
C          *CHECK FOR A NO PLOT REQUEST
            IF(NPLOT .GT. 0)THEN
C            *CHECK FOR TIME TO PLOT
             IF(NOLAY .EQ. NPLOT)THEN
C             *PLOT PRODUCTION AND NUMBER OF WELLS
              CALL PLOT(TPROD,TWELLS,YEARS,NPTS,NOLAY,IEOF,ICP)
              NOLAY=0
             END IF
            ELSE
```

BDM/A-81-763-TR

Figure A-3. GEODRL Computer LISTIN (Continued)

```
            NOLAY = 0
          END IF
          GO TO 1000
10000 CONTINUE
      STOP 'END OF INPUT AND GEODRL'
 9000  FORMAT(8H INITIAL,7X,F10.0,20X,2F10.0)
 9100  FORMAT(I5,10X,5F10.0)
 9200  FORMAT(I5,6F10.0)
      END
```

BDM/A-81-763-TR

Figure A-3. GEODRL Computer LISTIN (Continued)

```
      FUNCTION CMPC(IYEAR,IYRGRW,EEGR,RESPOT,IYRON)
      CMPC0=FLOAT(IYRON)
      CMPC=RESPOT/((RESPOT/CMPC0-1)*EXP(-EEGR*(IYEAR-IYRGRW))+1)
      RETURN
C**  THIS PROGRAM VALID ON FTN4 AND FTN5 **
      END


      FUNCTION CUBIC(COEF,TIME)
      DIMENSION COEF(5)
      CUBIC = COEF(1) + COEF(2)*TIME + COEF(3)*TIME**2 + COEF(4)*TIME**3
      RETURN
      END


      SUBROUTINE INIT(COEFRR,COEFTN,COEFWP,GRWRAT,IEOF,IYRGRW,IYRON,
     A NOLAY,NPLOT,NYCOM,NYRW,RESPOT,RIWF)
      DIMENSION COEFRR(5),COEFTN(5),COEFWP(5)
C     *INITIALIZE PARAMETERS
       COEFRR(1) = 0.044
       COEFTN(1) = 2.0
       COEFWP(1) = 4.0
       DO 100 I=2,5
         COEFRR(I) = 0.
         COEFTN(I) = 0.
         COEFWP(I) = 0.
 100     CONTINUE
       GRWRAT = 0.2
       IEOF = 0
       IYRGRW = 1986
       IYRON = 200
       NOLAY = 0
       NPLOT = 0
       NYCOM = 3
       NYRW = 1
       RESPOT = 7000.
       RIWF = 0.5
      PRINT*,' '
      PRINT*,' '
      PRINT*,'     G E O D R L 5   R U N '
      PRINT*,' '
      PRINT*,' GEODRL COMPUTES PRODUCTION AND NUMBER OF WELLS DRILLED'
      PRINT*,' BETWEEN START YEAR AND THE YEAR 2000 BASED ON THE'
      PRINT*,' FOLLOWING PARAMETER VALUES. YOU MAY CHANGE ANY VALUE'
      PRINT*,' BY ENTERING A NEW VALUE WHEN GEODRL PROMPTS YOU WITH A'
      PRINT*,' <?>. IF YOU DO NOT WISH TO CHANGE A VALUE ENTER A COMMA'
      PRINT*,' FOLLOWED BY A <CR>. IF YOU WISH TO TERMINATE THE RUN'
      PRINT*,' ENTER A <CR> RIGHT AFTER THE <?>.'
      PRINT*,' '
      RETURN
      END
```


Figure A-3. GEODRL Computer LISTIN (Continued)

```
      SUBROUTINE INPRO(RESPOT,IYRON,IYRGRW,NYCOM,NYRW,COEFWP,COEFTN,
     $ COEFRR,GRWRAT,NPLOT,RIWF,IEOF,NOLAY,ICP)
      DIMENSION COEFWP(5),COEFTN(5),COEFRR(5), ICP(4)
      CHARACTER IYES*1, IANSER*1
      DATA ICASE/0/, IYES/'Y'/
      IF(IEOF.EQ.1)GO TO 20000
      ICASE = ICASE + 1
      ICP(NOLAY + 1) = ICASE
      IF(NOLAY .EQ. 0)GO TO 50
        ASSIGN 2000 TO JUMP
        PRINT*,' '
        PRINT*,'NOW CHANGE PARAMETERS IN CASE ',ICASE-1,
     $' TO GENERATE CURVE ',NOLAY+1
      PRINT*,'  BEGIN ENTERING CASE ',ICASE,' VALUES'
        GO TO 3000
   50 ASSIGN 150 TO JUMP
      PRINT*,' '
      PRINT*,' '
      PRINT*,'BEGIN ENTERING NEW VALUES FOR CASE ',ICASE
      PRINT*,' '
  100 PRINT*,' 1;MAXIMUM POTENTIAL PRODUCTION OF RESERVOIR=',RESPOT,
     $ '(MEGAWATTS)'
      READ(*,*,END=10000)RESPOT
      GO TO JUMP
  150 ASSIGN 250 TO JUMP
  200 PRINT*,' 2;FIRST YEAR ON-LINE PRODUCTION=',IYRON,'(MEGAWATTS)'
      READ(*,*,END=10000)IYRON
      GO TO JUMP
  250 ASSIGN 350 TO JUMP
  300 PRINT*,' 3;YEAR GROWTH STARTS=',IYRGRW
      READ(*,*,END=10000)IYRGRW
      GO TO JUMP
  350 ASSIGN 450 TO JUMP
  400 PRINT*,' 4;NUMBER OF YEARS NEW WELLS MUST BE DRILLED BEFORE',
     $ ' PLANT IS COMMISSIONED=',NYCOM
      READ(*,*,END=10000)NYCOM
      GO TO JUMP
  450 ASSIGN 550 TO JUMP
  500 PRINT*,' 5;NUMBER OF YEARS REPLACMENT WELLS MUST BE DRILLED',
     $ ' BEFORE NEEDED=',NYRW
      READ(*,*,END=10000)NYRW
      GO TO JUMP
  550 ASSIGN 650 TO JUMP
      PRINT*,' THREE SETS OF COEFICENTS FOR CUBIC FITS FOLLOW:'
      PRINT*,' ENTER NEW COEFICIENTS IN THE ORDER THEY APPEAR IN THE'
      PRINT*,' EQUATIONS (SEPARATE VALUES WITH COMMAS)'
      PRINT*,'  T=TIME SINCE GROWTH STARTS(YEARS)'
  600 PRINT*,' 6;WELL PRODUCTION=(',COEFWP(1),')+(',COEFWP(2),')*T+(',
     $ COEFWP(3),')*T**2+(',COEFWP(4),')*T**3'
      READ(*,*,END=10000)(COEFWP(I),I=1,4)
      GO TO JUMP
  650 ASSIGN 750 TO JUMP
```

BDM/A-81-763-TR

Figure A-3. GEODRL Computer LISTIN (Continued)

```
  700  PRINT*,' 7;(NEW WELLS)/(SUCCESSFUL WELLS)=(',COEFTN(1),')+(',
     $ COEFTN(2),')*T+(',COEFTN(3),')*T**2+(',COEFTN(4),')*T**3'
       READ(*,*,END=10000)(COEFTN(I),I=1,4)
       GO TO JUMP
  750  ASSIGN 850 TO JUMP
  800  PRINT*,' 8;REPLACMENT RATE=(',COEFRR(1),')+(',COEFRR(2),')*T+(',
     $ COEFRR(3),')*T**2+(',COEFRR(4),')*T**3'
       READ(*,*,END=10000)(COEFRR(I),I=1,4)
       GO TO JUMP
  850  ASSIGN 950 TO JUMP
  900  PRINT*,' 9;INITIAL PERCENTAGE GROWTH RATE=',GRWRAT
       READ(*,*,END=10000)GRWRAT
       GO TO JUMP
  950  ASSIGN 1050 TO JUMP
 1000  PRINT*,'10;INITIAL NUMBER OF WELLS FACTOR=',RIWF
       READ(*,*,END=10000)RIWF
       GO TO JUMP
 1050  ASSIGN 2000 TO JUMP
 1100  IF(NOLAY .EQ. 0)THEN
         PRINT*,'11;NUMBER OF CURVES ON ONE SET OF GRAPHS=',NPLOT
         READ(*,*,END=10000)NPLOT
       END IF
       GO TO JUMP
 2000  PRINT*,' '
       PRINT*,' DO YOU WISH TO REENTER ANY VALUES(NO/YES)'
       READ(*,90000,END=10000)IANSER
       IF(IANSER .NE. IYES)GO TO 20000
 3000    PRINT*,' WHICH PARAMETER DO YOU WISH TO REENTER'
         READ(*,*,END=10000)IGO
         IF(IGO.LT.1.OR.IGO.GT.13)GO TO 3000
         GO TO (100,200,300,400,500,600,700,800,900,1000,1100),IGO
10000  IEOF = 1
20000  CONTINUE
       RETURN
90000  FORMAT(A1)
       END
```

BDM/A-81-763-TR

Figure A-3. GEODRL Computer LISTIN (Continued)

```
      SUBROUTINE PLOT(TPROD,TWELLS,YEARS,NPTS,NOLAY,IEOF,ICP)
      DIMENSION TPROD(30,4),TWELLS(30,4),YEARS(30,4),NPTS(4),RANGE(5),
     A  ICP(4), IPLTC(4)
      CHARACTER IYES*1, IPLTC*1, IANSER*1
      DATA PRODMX/3000./, WELLMX/3000./, IYES/'Y'/
      IPLTC(1)='*'
      IPLTC(2)='+'
      IPLTC(3)='3'
      IPLTC(4)='4'
C     *READ IN MAX AND MIN VALUES FOR PLOTS
1000  PRINT*,' '
      PRINT*,' '
       PRINT*,'MAXIMUM PRODUCTION VALUE FOR PLOT=',PRODMX,
     $   '(MEGAWATTS)'
       READ(*,*,END=10000)PRODMX
C     *SET UP FOR PLOTTING PRODUCTION
      RANGE(1)=1.
      RANGE(2)=1980.
      RANGE(3)=2000.
      RANGE(4)=0.
      RANGE(5)=PRODMX
      PRINT*,'PRODUCTION'
      PRINT*,'MEGAWATTS'
      CALL XPPLOT(-49061,0,0,1,0,0,0,RANGE,NOLAY,
     A YEARS(1,1),TPROD(1,1),NPTS(1),'*',
     B YEARS(1,2),TPROD(1,2),NPTS(2),'+',
     C YEARS(1,3),TPROD(1,3),NPTS(3),'3',
     D YEARS(1,4),TPROD(1,4),NPTS(4),'4')
      PRINT*,'                                        YEAR'
      DO 1500 I=1,NOLAY
1500  PRINT 1600,IPLTC(I),ICP(I)
1600  FORMAT('  ',A1,'=CASE NUMBER ',I2)
     PRINT*,' '
     PRINT*,' '
     PRINT*,' IS PLOT OK'
     READ(*,9000,END=10000)IANSER
9000 FORMAT(A1)
     IF(IANSER .NE. IYES)GO TO 1000
C    *READ IN MAX VALUE FOR NUMBER OF WELLS PLOT
2000 PRINT*,' '
     PRINT*,' '
       PRINT*,'MAXIMUM NUMBER OF WELLS VALUE FOR PLOT=',WELLMX,
     $   '(WELLS)'
       READ(*,*,END=10000)WELLMX
C     *SET UP FOR PLOTTING TOTAL NUMBER OF WELLS DRILLED
      RANGE(5)=WELLMX
      PRINT*,' '
      PRINT*,' '
      PRINT*,'NUMBER OF WELLS'
      CALL XPPLOT(-49061,0,0,1,0,0,0,RANGE,NOLAY,
     A YEARS(1,1),TWELLS(1,1),NPTS(1),'*',
     B YEARS(1,2),TWELLS(1,2),NPTS(2),'+',
```

BDM/A-81-763-TR

Figure A-3. GEODRL Computer LISTIN (Continued)

```
     C YEARS(1,3),TWELLS(1,3),NPTS(3),'3',
     D YEARS(1,4),TWELLS(1,4),NPTS(4),'4')
       PRINT*,'                                        YEAR'
       DO 2500 I=1,NOLAY
2500   PRINT 1600,IPLTC(I),ICP(I)
      PRINT*,' '
      PRINT*,' '
      PRINT*,' IS PLOT OK'
      READ(*,9000,END=10000)IANSER
      IF(IANSER .NE. IYES)GO TO 2000
       RETURN
10000  IEOF = 1
       RETURN
       END


      SUBROUTINE XPPLOT(ISIZE,IPAGE,IBOX,ILABEL,IMARK,IAXES,ITYPE,RANGE,
     1              NUM,X1,Y1,N1,L1,X2,Y2,N2,L2,X3,Y3,N3,L3,X4,Y4,N4,L4)
C
C     SANDIA MATHEMATICAL PROGRAM LIBRARY
C     APPLIED MATHEMATICS DIVISION 2642
C     SANDIA LABORATORIES
C     ALBUQUERQUE, NEW MEXICO  87115
C     COMTROL DATA 6600/7600 VERSION 7.0  MARCH 1977
C
C   * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C   *                  ISSUED BY SANDIA LABORATORIES,
C   *                    A PRIME CONTRACTOR TO THE
C   *   UNITED STATES ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
C   * * * * * * * * * * * * * * NOTICE  * * * * * * * * * * * * * * * *
C   * THIS REPORT WAS PREPARED AS AN ACCOUNT OF WORK SPONSORED BY THE
C   * UNITED STATES GOVERNMENT.  NEITHER THE UNITED STATES NOR THE
C   * UNITED STATES ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION,
C   * NOR ANY OF THEIR EMPLOYEES, NOR ANY OF THEIR CONTRACTORS,
C   * SUBCONTRACTORS, OR THEIR EMPLOYEES, MAKES ANY WARRANTY, EXPRESS
C   * OR IMPLIED, OR ASSUMES ANY LEGAL LIABILITY OR RESPONSIBILITY
C   * FOR THE ACCURACY, COMPLETENESS OR USEFULNESS OF ANY INFORMATION,
C   * APPARATUS, PRODUCT OR PROCESS DISCLOSED, OR REPRESENTS THAT ITS
C   * USE WOULD NOT INFRINGE PRIVATELY OWNED RIGHTS.
C   * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C   * THE PRIMARY DOCUMENT FOR THE LIBRARY OF WHICH THIS ROUTINE IS
C   * A PART IS SAND75-0545.
C   * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C
C     ABSTRACT
C        XPPLOT PLOTS ONE TO FOUR CURVES ON A SINGLE PRINTER-TYPE PLOT.
C     THE PHYSICAL SIZE OF THE PLOT MAY BE VARIED AS APPROPRIATE FOR
C     PRINTER OR TERMINAL OUTPUT.  OPTIONS ARE SUPPLIED FOR AXIS
C     DRAWING AND LABELLING, SURROUNDING THE PLOT AREA WITH A BOX,
C     SPECIFYING SPECIAL PLOT LIMITS, PRODUCING BAR GRAPHS, ETC.
C     XPPLOT DOES NO OVER-PRINTING, SO IT MAY BE USED WITH HALF-DUPLEX
C     TERMINALS.
```


Figure A-3. GEODRL Computer LISTIN (Continued)

```
C
C     DESCRIPTION OF ARGUMENTS
C        ISIZE  - SIZE OF ACTUAL PLOT AREA, NOT INCLUDING LABELS, ETC.
C                  IF = 2, 4, 6, 8, 10, OR 12, THE PLOT SIZE WILL BE
C                    THAT MANY INCHES, HORIZONTALLY AND VERTICALLY.
C                    OR, ISIZE MAY BE OF THE FORM 100*IVERT+IHORZ, WHERE
C                    IVERT AND IHORZ ARE THE VERTICAL AND HORIZONTAL
C                    DIMENSIONS, IN INCHES, OF THE ACTUAL PLOT AREA.
C                    IN THIS CASE, IVERT AND IHORZ MUST EACH BE ONE OF
C                    THE VALUES 2, 4, 6, 8, 10, OR 12.
C                    WHEN USING A TERMINAL, IHORZ (OR ISIZE) SHOULD
C                    BE NO LARGER THAN 6.  WHEN USING A LINE PRINTER
C                    WITH AUTOMATIC PAGE EJECT AT PAGE BREAKS, IVERT
C                    (OR ISIZE) SHOULD BE NO LARGER THAN 8.
C                IF ISIZE.LT.0, ITS FORM MUST BE -(1000*NROW+NCOL),
C                    WHERE NROW IS THE NUMBER OF ROWS, OR PRINT LINES,
C                    TO BE USED, AND NCOL IS THE NUMBER OF COLUMNS,
C                    OR PRINT POSITIONS, PER LINE.  THERE ARE NO
C                    RESTRICTIONS ON NROW AND NCOL EXCEPT THAT THEY
C                    BE AT LEAST TWO, AND NCOL.LE.121.
C                    FOR EXAMPLE, ISIZE= -49101 WOULD PRODUCE A 49 ROW
C                    BY 101 COLUMN (8 BY 10 INCH) PLOT.
C                    LABELING OF THE AXES MAY NOT APPEAR NICELY REGULAR
C                    WHEN UNUSUAL VALUES ARE USED FOR NROW OR NCOL.
C                IF ISIZE=0, A 6 BY 6 INCH PLOT WILL BE DONE.
C                IF ISIZE=1, AN 8 BY 8 INCH PLOT WILL BE DONE.
C        IPAGE  - IF .GT.0, A PAGE EJECT WILL BE DONE BEFORE THE PLOT
C                    IS STARTED.
C                IF .LE.0, NO PAGE EJECT IS DONE.  THIS WOULD BE THE
C                    APPROPRIATE CHOICE FOR TERMINAL OUTPUT, OR IF
C                    YOU WISH TO PRINT A TITLE AT THE TOP OF THE PLOT.
C        IBOX   - IF =1, A BOX WILL BE DRAWN (WITH ASTERISKS) AROUND
C                    THE ACTUAL PLOT AREA (NOT INCLUDING LABELS, ETC.)
C                    USE OF A BOX IS NOT RECOMMENDED WHEN USING A
C                    TERMINAL, AS IT MAY SLOW DOWN PLOTTING TOO MUCH.
C                IF =2, THE BOX WILL BE DRAWN WITH PLUS SIGNS.
C                IF =3, THE BOX WILL BE DRAWN WITH ZEROES.
C                IF =4, THE BOX WILL BE DRAWN WITH THE LETTER X.
C                IF .LE.0, NO BOX WILL BE DRAWN AROUND THE PLOT AREA.
C        ILABEL - IF =0 OR ANY VALUE OTHER THAN 1, 2, 3, OR 6, BOTH
C                    AXES WILL BE LABELLED EVERY TWO INCHES.
C                IF =1, 2, 3, OR 6, THE Y AXIS WILL BE LABELLED EVERY
C                    WHOLE, HALF, THIRD, OR SIXTH OF AN INCH
C                    (ASSUMING SIX LINES ARE PRINTED PER VERTICAL INCH),
C                    WHILE X AXIS LABELLING REMAINS AT TWO INCHES.
C                IF .LT.0, LABELS WILL BE SUPPRESSED COMPLETELY.
C                    HOWEVER, IF IMARK.GE.0, THE MAGNITUDE OF ILABEL
C                    WILL STILL INDICATE THE TIC MARK SPACING.
C        IMARK  - IF .GT.0, TIC MARKS WILL MARK EACH ROW OR COLUMN
C                    BEING LABELLED.  THE LENGTHS OF THE MARKS WILL
C                    BE ROUGHLY IMARK/6 INCHES.  THUS, IF IMARK IS SET
```


Figure A-3. GEODRL Computer LISTIN (Continued)

```
C                    TO A LARGE NUMBER, SAY 100, THESE TIC MARKS WILL
C                    BECOME FULL GRID LINES.  NOTE -- THE X AXIS MAY
C                    NOT BE LABELLED MORE DENSELY THAN ONCE EVERY
C                    TWO INCHES.  HOWEVER, THE SPACING OF TIC MARKS
C                    ON THE X AXIS WILL EQUAL THAT OF THE Y AXIS
C                    EXCEPT WHEN IABS(ILABEL)=3 OR 6, IN WHICH CASE
C                    X AXIS TIC MARKS WILL REMAIN AT HALF INCH
C                    INTERVALS.
C                 IF .LT.0, NO TIC MARKS WILL BE USED.  IN THIS CASE,
C                    X AXIS LABELLING WILL BE SUPPRESSED, AS IT WOULD
C                    BE AMBIGUOUS.   THIS MODE MAY BE DESIRABLE WHEN
C                    PLOTTING HISTOGRAMS WITH ITYPE=2.
C                 IF =0, SINGLE CHARACTER MARKS WILL BE USED.
C        IAXES  - IF .GT.0, X- AND Y-AXES WILL BE DRAWN ON THE PLOT, SO
C                    AS TO PASS AS CLOSELY AS POSSIBLE THROUGH X=0, Y=0.
C                 IF .LE.0, NO AXES WILL BE DRAWN.
C        ITYPE  - IF .LE.1, A NORMAL PLOT WILL BE DONE.
C                 IF =2, A HORIZONTAL BAR GRAPH WILL BE DRAWN.
C                    THIS MEANS THAT THE OCCURANCE OF A DATA POINT
C                    ON A CURVE CAUSES THE PLOT CHARACTER FOR
C                    THAT CURVE TO BE PRINTED IN THE ROW/COLUMN
C                    POSITION INDICATED BY THAT POINT, PLUS IN ALL
C                    COLUMNS OF THAT ROW TO THE LEFT OF THAT POINT.
C                    HOWEVER, A HIGHER PRIORITY CURVE MAY THEN
C                    OVERPLOT SOME OR ALL OF THAT ROW OF CHARACTERS.
C                    SEE NOTE AT BOTTOM.
C                 IF .GE.3, A VERTICAL BAR GRAPH WILL BE DRAWN.
C                    THAT IS, A GIVEN POINT CAUSES ITS PLOT CHARACTER
C                    TO BE PLOTTED IN A GIVEN ROW/COLUMN POSITION,
C                    PLUS IN ALL ROWS BELOW THAT POSITION.
C                    HOWEVER, IF ANOTHER DATA POINT APPEARS LATER
C                    (I.E., LOWER) IN THIS COLUMN, IT WILL TAKE
C                    PRECEDENCE FOR THAT ROW AND BELOW.
C                    NOTE -- YOU SHOULD NOT USE IMARK.GT.1 OR
C                    IAXES.GT.0 WHEN ITYPE=3, AS ANYTHING PRINTED ON THE
C                    ACTUAL PLOT AREA WILL PROPAGATE BELOW THAT
C                    POINT JUST AS IF IT WERE DATA.
C        RANGE  - IF RANGE=0., THE PLOT SCALES WILL BE DETERMINED BY
C                    THE DATA.  IN THIS CASE, THE MIDDLE OF THE FIRST
C                    COLUMN WILL CORRESPOND TO THE MINIMUM X VALUE,
C                    THE MIDDLE OF THE LAST COLUMN WILL CORRESPOND TO
C                    THE MAXIMUM X VALUE, THE MIDDLE OF THE BOTTOM ROW
C                    WILL CORRESPOND TO THE MINIMUM Y VALUE, AND
C                    THE MIDDLE OF THE TOP ROW WILL CORRESPOND TO THE
C                    MAXIMUM Y VALUE.
C                 IF RANGE.NE.0., THEN RANGE IS ASSUMED TO BE AN ARRAY
C                    OF LENGTH 5, CONTAINING THE FOLLOWING.
C                       RANGE(1) - A NON-ZERO VALUE.
C                       RANGE(2) - X VALUE OF LEFT-MOST COLUMN
C                       RANGE(3) - X VALUE OF RIGHT-MOST COLUMN
C                       RANGE(4) - Y VALUE OF BOTTOM ROW
```

BDM/A-81-763-TR

Figure A-3. GEODRL Computer LISTIN (Continued)

```
C                          RANGE(5) - Y VALUE OF TOP ROW
C                        THESE RANGE PARAMETERS MAY BE USED EITHER TO
C                        EXTEND OR RESTRICT THE NORMAL RANGE.  THAT IS,
C                        THEY MAY BE USED TO ZOOM OUT OR IN.
C         NUM     - NUMBER OF CURVES BEING USED FOR THIS PLOT.
C                   IF NUM=1, THE CALLING SEQUENCE MAY BE TERMINATED
C                   AFTER THE PARAMETER L1.  (MOST FORTRAN COMPILERS
C                   WILL TOLERATE THIS USAGE.)  IF NUM=2, THE CALLING
C                   SEQUENCE MAY BE TERMINATED AFTER PARAMETER L2, ETC.
C                   IF NUM=0, ONE CURVE WILL BE ASSUMED.
C         X1      - ARRAY OF X-COORDINATES FOR FIRST CURVE.
C         Y1      - ARRAY OF Y-COORDINATES FOR FIRST CURVE.
C         N1      - NUMBER OF DATA POINTS ON FIRST CURVE (DIMENSION OF
C                   X1 AND Y1).
C         L1      - PLOT CHARACTER TO BE USED FOR FIRST CURVE.  THIS
C                   CHARACTER SHOULD BE IN A1 FORMAT, SUCH AS '*'.
C         X2,Y2,N2,L2 - CORRESPONDING DATA FOR SECOND CURVE.
C         X3,Y3,N3,L3 - CORRESPONDING DATA FOR THIRD CURVE.
C         X4,Y4,N4,L4 - CORRESPONDING DATA FOR FOURTH CURVE.
C                   NOTE -- IN CASE DATA FROM MORE THAN ONE CURVE OCCURS
C                        AT A GIVEN ROW/COLUMN POSITION, SYMBOL L1 WILL
C                        OVERRIDE SYMBOL L2, WHICH WILL OVERRIDE SYMBOL L3,
C                        ETC.
C
C      FORMAT
C         THE FORMAT USED FOR THE PLOT AREA IS
C         FORMAT (1X,G11.4,A1,NA1,A1)
C         WHERE NA1 IS THE ACTUAL PLOT AREA, AND THE TWO A1 FIELDS
C         ARE FOR THE BOX AND TIC MARKS.
C
C      SOME SIMPLE EXAMPLES --
C         A TYPICAL TERMINAL PLOT OF A SINGLE FUNCTION CAN BE DONE BY
C            CALL XPPLOT(0,0,0,0,0,0,0,0.,1,X,Y,N,'*')
C         A TYPICAL LINE PRINTER PLOT OF A SINGLE FUNCTION CAN BE DONE BY
C            CALL XPPLOT(1,1,1,1,1,1,1,0.,1,X,Y,N,'*')
C         A TYPICAL LINE PRINTER PLOT OF TWO DEPENDENT VARIABLES
C         AGAINST A SINGLE INDEPENDENT VARIABLE CAN BE DONE BY
C            CALL XPPLOT(1,1,1,1,1,1,1,0.,2,X,Y1,N,'1',X,Y2,N,'2')
C
C      R E JONES  DIVISION 2642  JUNE 1976
C
* END OF ABSTRACT
      LOGICAL K1,K2,K3,K4,KYLAB,KXLAB,KLLAB,KPLOT,KVERT,KHORZ
      DIMENSION RANGE(5)
      DIMENSION X1(N1),Y1(N1),X2(N2),Y2(N2),X3(N3),Y3(N3),X4(N4),Y4(N4)
      DIMENSION LINE(123),XSCALE(7)
      CHARACTER LBLANK*1,LSTAR*1,LPLUS*1,LVERT*1,LHORZ*1,LZERO*1,LETX*1
      CHARACTER IBOXCH*1, LINE*1, L1*1, L2*1, L3*1, L4*1
      DATA LBLANK/' '/,LSTAR/'*'/,LPLUS/'+'/,LVERT/'I'/,LHORZ/'-'/
      DATA LZERO/'0'/,LETX/'X'/
C     THE FOLLOWING CALL TO MLUSED IS PRESENT SOLELY TO MONITOR USAGE
```

BDM/A-81-763-TR

Figure A-3. GEODRL Computer LISTIN (Continued)

```
C       OF THIS ROUTINE AT SLA AND MAY BE DELETED.
C       CALL MLUSED
C INITIALIZE
        K1 = .TRUE.
        K2 = (NUM.GE.2)
        K3 = (NUM.GE.3)
        K4 = (NUM.GE.4)
C
        IF (K1) K1 = (N1.GT.0)
        IF (K2) K2 = (N2.GT.0)
        IF (K3) K3 = (N3.GT.0)
        IF (K4) K4 = (N4.GT.0)
        IF (.NOT.(K1.OR.K2.OR.K3.OR.K4)) RETURN
C (DETERMINE PLOT SIZE)
        LSIZE = ISIZE
        IF (.NOT.(ISIZE.GE.0)) GO TO 10
C       THEN
           IF (LSIZE.EQ.0) LSIZE = 6
           IF (LSIZE.EQ.1) LSIZE = 8
           IVERT = LSIZE/100
           IF (IVERT.LE.0) IVERT = LSIZE
           IVERT = MAX0(IVERT,2)
           IVERT = MIN0(IVERT,12)
           IVERT = (IVERT/2)*2
           NROW = 6*IVERT+1
           IHORZ = MOD(LSIZE,100)
           IF (IHORZ.LE.0) IHORZ = LSIZE/100
           IHORZ = MAX0(IHORZ,2)
           IHORZ = MIN0(IHORZ,12)
           IHORZ = (IHORZ/2)*2
           NCOL = 10*IHORZ+1
           GO TO 20
C       ELSE
   10      NROW = (-LSIZE)/1000
           NCOL = MOD(-LSIZE,1000)
           NCOL = MIN0(NCOL,121)
           IF ((NROW.GE.2).AND.(NCOL.GE.2)) GO TO 15
C             DEFAULTS WHEN ISIZE IS INVALID.
              NROW = 37
              NCOL = 61
   15      CONTINUE
   20 CONTINUE
        NCOLP2 = NCOL+2
        NCOLM1 = NCOL-1
        NROWP2 = NROW+2
C (DETERMINE BOX CHARACTER)
        IBOXCH = LSTAR
        IF (IBOX.GE.2) IBOXCH = LPLUS
        IF (IBOX.GE.3) IBOXCH = LZERO
        IF (IBOX.GE.4) IBOXCH = LETX
        IF (IBOX.LE.0) IBOXCH = LBLANK
C (LABELLING AND MARKING PARAMETERS)
```


Figure A-3. GEODRL Computer LISTIN (Continued)

```
      KYLAB = (ILABEL.GE.0)
      KXLAB = (ILABEL.GE.0).AND.(IMARK.GE.0)
      NLABEL = IABS(ILABEL)
      IF ((NLABEL.NE.1).AND.(NLABEL.NE.2).AND.
     1    (NLABEL.NE.3).AND.(NLABEL.NE.6)) NLABEL = 0
      IYINC = 12
      IF (NLABEL.GE.1) IYINC = MAX0(1 , 6/NLABEL)
      IXINC = 20
      IF (NLABEL.GE.1) IXINC = MAX0(5 , 10/NLABEL)
      IF (IMARK.LT.0) GO TO 30
         NVMARK = MAX0(1,IMARK)
         NHMARK = (10*NVMARK)/6
         NHMARK = MIN0((NCOLP2+1)/2 , NHMARK)
         MARK1 = NCOLP2-NHMARK+1
   30 CONTINUE
C (PLOT RANGE)
      IF (.NOT.(RANGE(1).EQ.0.)) GO TO 40
C     THEN COMPUTE RANGE
         INIT = 0
         IF (K1) CALL XPMNMX(X1,N1,XMIN,XMAX,INIT)
         IF (K2) CALL XPMNMX(X2,N2,XMIN,XMAX,INIT)
         IF (K3) CALL XPMNMX(X3,N3,XMIN,XMAX,INIT)
         IF (K4) CALL XPMNMX(X4,N4,XMIN,XMAX,INIT)
         IHORZ=(NCOL-1)/10
         CALL SCALE(IHORZ,XMIN,XMAX)
         INIT = 0
         IF (K1) CALL XPMNMX(Y1,N1,YMIN,YMAX,INIT)
         IF (K2) CALL XPMNMX(Y2,N2,YMIN,YMAX,INIT)
         IF (K3) CALL XPMNMX(Y3,N3,YMIN,YMAX,INIT)
         IF (K4) CALL XPMNMX(Y4,N4,YMIN,YMAX,INIT)
         IVERT=(NROW-1)/6
         CALL SCALE(IVERT,YMIN,YMAX)
         GO TO 50
C     ELSE FETCH RANGE
   40    XMIN = RANGE(2)
         XMAX = RANGE(3)
         YMIN = RANGE(4)
         YMAX = RANGE(5)
   50 CONTINUE
      IF (XMIN.GE.XMAX) XMAX = XMIN+1.0
      IF (YMIN.GE.YMAX) YMAX = YMIN+1.0
C (ROW AND COLUMN SPACINGS)
      DX = (XMAX-XMIN)/FLOAT(NCOL-1)
      DY = (YMAX-YMIN)/FLOAT(NROW-1)
      XL = XMIN - 0.5*DX
      YB = YMAX + 1.5*DY
C (AXIS PARAMETERS)
      IYAXCL = (0.-XL)/DX + 1.0
      IF ((IYAXCL.LE.0).OR.(IYAXCL.GT.NCOL)) IYAXCL = 0
C LINE LOOP - INCLUDING BOX
      IF (IPAGE.GE.1) WRITE (*,60)
   60 FORMAT (1H1)
```

BDM/A-81-763-TR

Figure A-3. GEODRL Computer LISTIN (Continued)

```
      DO 500 IROWP1 = 1,NROWP2
         IROW = IROWP1-1
         KPLOT = (IROW.GE.1).AND.(IROW.LE.NROW)
         KHORZ = KPLOT.AND.((MOD(IROW,IYINC).EQ.1).OR.
     1         (IYINC.EQ.1).OR.(IROW.EQ.NROW))
         YT = YB
         YB = YB - DY
         IF ((ITYPE.GE.3).AND.(IROW.GT.1)) GO TO 90
C        ELSE CLEAR LINE IMAGE
            DO 80 I=1,NCOLP2
   80          LINE(I) = LBLANK
   90    CONTINUE
C (BOX)
         IF (KPLOT) GO TO 110
C        ELSE DO BOX TOP OR BOTTOM
            DO 100 I=1,NCOLP2
  100          LINE(I) = IBOXCH
  110    CONTINUE
         LINE(1) = IBOXCH
         LINE(NCOLP2) = IBOXCH
C (TIC MARKS)
         IF (IMARK.LT.0) GO TO 200
            IF (.NOT.KHORZ) GO TO 170
C           ELSE DRAW HORIZONTAL TICS
               DO 150 I=1,NHMARK
  150             LINE(I) = LHORZ
               DO 160 I=MARK1,NCOLP2
  160             LINE(I) = LHORZ
  170       CONTINUE
            KVERT = (IROWP1.LE.NVMARK).OR.(NROWP2-IROWP1.LT.NVMARK)
            IF (.NOT.KVERT) GO TO 190
C           ELSE DRAW VERTICAL TICS.  USE PLUS SIGNS WHERE TICS CROSS.
               DO 180 I=2,NCOL,IXINC
                  LINE(I) = LVERT
                  IF (KHORZ.AND.((I.LE.NHMARK).OR.(I.GE.MARK1)))
     1                 LINE(I) = LPLUS
  180          CONTINUE
               LINE(NCOL+1) = LVERT
               IF (KHORZ.AND.(NCOL+1.GE.MARK1)) LINE(NCOL+1) = LPLUS
  190       CONTINUE
  200    CONTINUE
C (LABELS)
         KLLAB = KHORZ.AND.KYLAB
         IF (.NOT.KLLAB) GO TO 205
            YM = 0.5*(YT+YB)
            IF (ABS(YM).LT.1.0E-6*(YMAX-YMIN)) YM = 0.
  205    CONTINUE
C (AXES)
         IF ((IAXES.LE.0).OR.(.NOT.KPLOT)) GO TO 230
C        ELSE
            IF (IYAXCL.GT.0) LINE(IYAXCL+1) = LVERT
            IF ((YB.GE.0.).OR.(YT.LT.0.).OR.(.NOT.KPLOT)) GO TO 220
```

BDM/A-81-763-TR

Figure A-3. GEODRL Computer LISTIN (Continued)

```
C            ELSE DRAW X AXIS
                DO 210 I=1,NCOL
  210              LINE(I+1) = LHORZ
                IF (IYAXCL.GT.0) LINE(IYAXCL+1) = LPLUS
  220        CONTINUE
  230     CONTINUE
C (CURVES)
          IF (.NOT.KPLOT) GO TO 240
          IF (K4) CALL XPSYMB(LINE(2),X4,Y4,N4,L4,XL,DX,YB,YT,NCOL,ITYPE)
          IF (K3) CALL XPSYMB(LINE(2),X3,Y3,N3,L3,XL,DX,YB,YT,NCOL,ITYPE)
          IF (K2) CALL XPSYMB(LINE(2),X2,Y2,N2,L2,XL,DX,YB,YT,NCOL,ITYPE)
          IF (K1) CALL XPSYMB(LINE(2),X1,Y1,N1,L1,XL,DX,YB,YT,NCOL,ITYPE)
  240     CONTINUE
C (PRINT)
          K = NCOLP2
C         IF ANY CHARACTER IS NON-BLANK
          DO 250 I=1,NCOLP2
             IF (LINE(K).NE.LBLANK) GO TO 260
  250        K = K-1
C         ELSE
             IF (.NOT.KLLAB) WRITE (*,280)
             IF (  KLLAB   ) WRITE (*,280) YM
             GO TO 270
C         THEN
  260        IF (.NOT.KLLAB) WRITE (*,290) (LINE(I),I=1,K)
             IF (  KLLAB   ) WRITE (*,280) YM,(LINE(I),I=1,K)
  270     CONTINUE
  280     FORMAT (1X,G11.4,123A1)
  290     FORMAT (12X,123A1)
  500 CONTINUE
C X-AXIS LABELS
       IF (.NOT.KXLAB) GO TO 600
          K = 0
          DO 510 I=1,NCOLM1,20
             K = K+1
             XSCALE(K) = XMIN + FLOAT(I-1)*DX
  510     CONTINUE
          K = K+1
          XSCALE(K) = XMAX
          DO 515 I=1,K
             IF (ABS(XSCALE(I)).LT.1.0E-6*(XMAX-XMIN)) XSCALE(I) = 0.
  515     CONTINUE
          WRITE (*,520) (XSCALE(I),I=1,K)
  520     FORMAT (8X,5(G11.4,9X),G11.4,7X,G11.4)
  600 CONTINUE
      RETURN
      END
```

BDM/A-81-763-TR

Figure A-3. GEODRL Computer LISTIN (Continued)

```
      SUBROUTINE XPSYMB(LINE,X,Y,N,LSYM,XL,DX,YB,YT,NCOL,ITYPE)
C
C     INSERT SYMBOLS FOR A CURVE INTO THE LINE IMAGE
C
* END OF ABSTRACT
      DIMENSION LINE(NCOL),X(N),Y(N)
      CHARACTER LINE*1, LSYM*1
      YYB = YB
      YYT = YT
      NN = N
      MIX = 0
      DO 10 I=1,NN
         IF (Y(I).LE.YYB) GO TO 10
         IF (Y(I).GT.YYT) GO TO 10
         IX = (X(I)-XL)/DX + 1.0
         IF ((IX.LT.1).OR.(IX.GT.NCOL)) GO TO 10
         LINE(IX) = LSYM
         MIX = MAX0(MIX,IX)
   10 CONTINUE
      IF ((ITYPE.NE.2).OR.(MIX.LE.0)) GO TO 30
         DO 20 I=1,MIX
   20      LINE(I) = LSYM
   30 CONTINUE
      RETURN
C**  THIS PROGRAM VALID ON FTN4 AND FTN5 **
      END


      SUBROUTINE XPMNMX(X,N,XMIN,XMAX,INIT)
C
C     RANGE COMPUTATION
C
* END OF ABSTRACT
      DIMENSION X(N)
      IF (N.LT.1) GO TO 30
         IF (INIT.GE.1) GO TO 10
            XMIN = X(1)
            XMAX = X(1)
            INIT = 1
   10    CONTINUE
         DO 20 I=1,N
            XMIN = AMIN1(XMIN,X(I))
            XMAX = AMAX1(XMAX,X(I))
   20    CONTINUE
   30 CONTINUE
      RETURN
C**  THIS PROGRAM VALID ON FTN4 AND FTN5 **
      END
```


Figure A-3. GEODRL Computer LISTIN (Concluded)

References

1. G. L. Brown, A. J. Mansure, and J. N. Miewald. Geothermal Wells: A Forecast of Drilling Activity, SAND 81-7127, (Albuquerque, New Mexico: Prepared for Sandia National Labs by The BDM Corporation, July 1981).

2. "On Location", GRC Bulletin, Vol. 10, No. 11, December 1981.

3. Geothermal Demonstration Power Plant: Vol. II Technical and Management Proposal, Submitted to DOE San Franscisco by Public Service Co. of New Mexico and Union Oil, January 31, 1978.

4. "On Location", GRC Bulletin, Vol. 10, No. 9, October 1981.

5. Planta Geotérmica de Cerro Prieto, Comisión Federal de Electricidad, Mexico.

6. "Assessment of Geothermal Resources of the United States - 1978," U.S. Geological Survey Circular 790, 1979.

7. Vane E. Suter, "The Application of Petroleum Engineering to Geothermal Development," Geothermal Energy, Vol. 9, No. 4, April 1981.

8. GRC Bulletin, Vol. 10, No. 3, April 1981.

9. GRC Bulletin, Vol. 9, No. 6, June 1980.

10. GRC Bulletin, Vol. 10, No. 6., July 1981.

11. S. H. Ward, et. al., "A Summary of the Geology, Geochemistry, and Geographics of the Roosevelt Hot Springs Thermal Area, Utah," Geophysics, Vol. 43, No. 7, December 1978.

12. W. J. Ehni, "Summary of 1980 Geothermal Drilling Western United States," Geothermal Energy, Vol. 9, No. 8, August 1981. (Also previous "Summary" articles in Geothermal Energy by Ehni, et. al. from 1976 to 1979.)

13. The Geyser, Vol. 7, No. 5, 29 November 1980.

14. L. H. Eilers, et al; Development of Geothermal Well Completion Systems, Phase I Report COO/4190-1 (July - September 1977).

15. Geothermal Loop Experimental Facility, Final Report, SDG&E, DOE/ET/28443-T1 (April 1980).

16. E. J. Zais, and G. Bodvarsson, "Analysis of Production Decline in Geothermal Reservoirs," Geothermal Reservoir Engineering Management Program, September 1980.

17. "Steam Production at The Geysers Geothermal Field," Geothermal Energy, eds. P. Kruger and C. Otte (Stanford: Stanford University Press, 1973).

18. C. C. Carson, and Y. T. Lin, "Geothermal Well Costs and Their Sensitivities to Changes in Drilling and Completion Operations," Proceedings of the International Conference on Geothermal Drilling and Completion Technology, SAND 81-0036C, 1981.

19. The Geyser, Volume 7, Issue 2, September 8, 1980.

20. NOS News Notes, Sandia National Laboratories, use latest version.

21. FORTRAN Version 5 Reference Manual, Publication No. 60481300 (Control Data Corporation).

DO NOT MICROFILM

DISTRIBUTION:
TID-4500-R66-UC-66c (507)

Tom Anderson
Venture Innovations
P.O. Box 35845
Houston, Texas 77035

Ed Bingman
Shell Oil Company
Two Shell Plaza
P.O. Box 2099
Houston, Texas 77001

Larry Diamond
Dyna-Drill
P.O. Box C-19576
Irvine, California 92713

John E. Fontenot
NL Petroleum Services
P.O. Box 60087
Houston, Texas 77205

Dr. Melvin Friedman
Professor of Geology
Center for Tectonophysics
and Dept. of Geology
Texas A&M University
College Station, Texas 77843

Tom Turner
Phillips Petroleum Company
Geothermal Operations
655 East 4500 South
Salt Lake City, Utah 84107

Jim Kingsolver
Smith Tool
Geothermal Operations
P.O. Box C-19511
Irvine, California 92713

James W. Langford
Security Division
Dresser Industries, Inc.
P.O. Box 24647
Dallas, Texas 75224

B. J. Livesay
Livesay Consultants
129 Liverpool
Cardiff, California 92007

Harvey E. Mallory
P.O. Box 54696
Tulsa, Oklahoma 74155

Ed Martin
Superior Oil
Eastern Division
P.O. Box 51108 OCS
Lafayette, Louisiana 70505

Gene Polk
NL Baroid
6400 Uptown Blvd., 365W
Albuquerque, New Mexico 87110

Del E. Pyle
Union Geothermal Division
Union Oil Co. of California
Union Oil Center
Los Angeles, California 90017

John C. Rowley
Los Alamos National Labs
Mail Stop 570
Los Alamos, New Mexico 87545

William D. Rumbaugh
Research and Development
Otis
P.O. Box 34380
Dallas, Texas 75234

Dwight Smith
Halliburton
Drawer 1431
Duncan, Oklahoma 73533

Tom Warren
Amoco Production Company
Research Center
P.O. Box 591
Tulsa, Oklahoma 74102

DISTRIBUTION (Cont.)

U.S. Department of Energy (6)
Geothermal Hydropower
Technologies Division
Forrestal Bldg., CE 324
1000 Independence Ave. S.W.
Washington, D.C. 20585
Attn: J. Bresee
D. Clements
R. Toms
D. Allen
G. Ellis

U.S. Department of Energy
Geopressure Projects Office
Suite 8620, Federal Bldg.
515 Rusk Street
Houston, Texas 77002
Attn: F. L. Goldsberry

3141 L. J. Erickson (5)
3151 W. L. Garner (3)
9000 G. A. Fowler
9700 E. H. Beckner
9740 R. K. Traeger
9741 J. R. Kelsey (10)
9741 B. C. Caskey
9743 H. C. Hardee
9746 B. Granoff
9747 P. J. Hommert
9750 V. L. Dugan
8214 M. A. Pound

☆ U.S. GOVERNMENT PRINTING OFFICE: 1982-0-576-021/585