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TECHNICAL REVIEW OF THE

LOS ALAMOS NATIONAL LABORATORY'S REPORT:

EVALUATION OF THE ST. LUCIA GEOTHERMAL RESOURCE

for

AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D. C.

by

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Richmond, California

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CONCLUSIONS AND RECOMMENDATIONS

We agree with Los Alamos National Laboratory (LANL) that the Qualibou caldera prospect has an excellent geothermal potential and that it is probable that geothermal energy will be economically competitive with available alternate energy resources. However, before consideration should be given to further exploration drilling, we recommend that the following tasks be completed:

1. Prior drilling of 7 wells in the Qualibou caldera to a maximum depth of 2,381 feet has resulted in the production of only about 3 MW-equivalent of steam. That drilling program, and resulting well test data, should be reviewed in detail to determine and document the reasons for the poor results; and also to identify information that could help ensure that a second drilling campaign will be more successful. For example transient pressure data from the original well tests should be examined, to determine if poor productivity is the result of (a) low permeability or (b) well damage from the loss of drilling mud into potentially productive steam zones.

2. Geologic mapping by LANL leaves unresolved the location and geometry of the fault which is channeling thermal fluid to the surface as hot springs in Sulphur Springs Valley. These hot springs are the most impressive thermal features in the Qualibou caldera, and, for possible drilling decisions, it is important to know the geometry of the permeable feature responsible for their occurrence. Because 6 of the 7 existing wells are located close to these springs, detailed cross-sections should be drawn across Sulphur Spring Valley, incorporating as much information as possible from the wells, including stratigraphy, subsurface temperature distribution, and the location of steam entry zones.

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3. Results of geochemical work give credible indications of high temperature at depth beneath the Qualibou caldera, but the results are not useful for locating a specific drilling target. No additional geochemical work is recommended.

4. No conclusions can be drawn from the single dipole-dipole resistivity pseudosection presented by LANL, because near-surface lateral variations in resistivity greatly effect the apparent resistivity values detected from greater depths. Furthermore, it is our experience that geologically valid resistivity interpretations cannot be made in volcanic terrains from a single profile. Knowledge of the areal distribution of resistivity, at various depth intervals, is also required. Consequently, we recommend that an integrated interpretation be made of all the available resistivity data, including the dipole-dipole surveys executed by the United Kingdom team, and the AMT surveys executed by Aquater. This interpretation should include computer modeling of all the dipole-dipole data to eliminate the effect of near-surface lateral variations in resistivity on the deeper resistivity values.

5. The LANL engineering report addresses a number of possibilities for geothermal development on St. Lucia. Each of the alternatives is treated rather lightly and with little depth. The next logical step is for the Government of St. Lucia to identify one or two geothermal applications that appear both economically viable and suitable to the needs of the St. Lucians. The most attractive applications should be studied in detail to verify the economic and technical aspects of the proposed geothermal development. These studies should include conceptual designs and detailed cost estimates to prove conclusively that a project has sufficient merit to proceed to a final design and construction stage. Otherwise, it is

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not worth continuing the project. A wellhead geothermal power plant is one alternative that is worthy of detailed study.

6. The LANL macroeconomics model provides little confidence in predicting trends in the gross domestic product (GDP) of St. Lucia. With such limited success, we feel that this effort is no more reliable than a simple extrapolation of the GDP with qualitative adjustments for major external events. The general result of the non-linear optimizing model (that a geothermal component in St. Lucia's energy mix would benefit the economy) can be accepted, but further work on this seems unjustified at this time.

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1. INTRODUCTION

GeothermEx, Inc. has been requested by the U. S. Agency for International Development (AID) to provide a systematic review of a report written by the Los Alamos National Laboratory (LANL) on technical and economic aspects of developing geothermal power on the island of St. Lucia. The report, entitled "Evaluation of the St. Lucia Geothermal Resource", has been issued in 4 parts:

a. Summary Report, April 1984
b. Geologic, Geophysical and Hydrogeologic Investigations, August 1984.
c. Engineering Investigation and Cost Estimate, August 1984; and
d. Macroeconomic Models, August 1984.

In addition to the LANL report, AID also provided GeothermEx with a copy of the October 1982 report, "Exploration of St. Lucia's Geothermal Reservoir", prepared by the Italian government-owned firm Aquater. This report documents the results of Aquater's geologic, geophysical and geochemical exploration efforts on the island during the early part of 1982. It is assumed that LANL had access to the Aquater reports at the time of its work. Both the LANL and Aquater reports have been reviewed by GeothermEx.

According to the terms of reference provided by AID, GeothermEx is requested to indicate areas of strength and weakness in both the technical and economic aspects of the LANL report, and to comment on the advisability of proceeding with work proposed by LANL.

Our comments are organized in 3 sections: The first is concerned with resource exploration; the second with surface plant engineering and

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cost estimates; and the third with macroeconomic models. This follows the organization of the LANL report.

The comments in our report pertaining to exploration were prepared by Dr. James R. McNitt, geologist and Vice President of GeothermEx for Exploration; Dr. Christopher W. Klein, senior geochemist; and Dr. William F. Isherwood, senior geophysicist, all of GeothermEx's staff. The report section dealing with plant engineering and costs, was prepared by the staff of Gibbs and Hill, Inc., a subsidiary of Dravo Corp., which is a consulting engineering firm with recent and extensive experience in the design, costing and construction of geothermal generating facilities in the western United States. The section on macroeconomic analysis was prepared by Dr. Isherwood, who holds an M.B.A. degree in addition to his Ph.D. in geophysics.

GeothermEx, Inc. was founded in 1973 to provide expertise in the exploration and development of geothermal energy. Its experience is worldwide, and includes discovery of the Miravalles geothermal field in Costa Rica, the Dixie Valley, Nevada, geothermal field (on behalf of Sunoco Energy Development Company) and step-out discoveries at The Geysers geothermal field, California. Other recent exploration/development experience has been in Japan, the Philippines, Yugoslavia, Indonesia, and Yemen, for investment agencies, agencies of national government and private companies. Prior to joining GeothermEx in 1980, Dr. McNitt was senior advisor on geothermal energy to the United Nations, and directed the successful Kenya project which resulted in discovery of the Olkaria geothermal field.

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2. TECHNICAL REVIEW OF EXPLORATION RESULTS

2.1 Geologic Studies

The three most important objectives of geologic mapping for geothermal exploration in volcanic areas are:

a. locating the area of most recent volcanic activity, which should coincide with the area of highest subsurface temperature;

b. locating and defining the geometry of faults which might provide structural permeability; and

c. identifying and determining the depth and thickness of formations which might provide stratigraphic permeability.

The Los Alamos work has clearly met the first objective by identifying the emplacement of Belfond domes as the most recent volcanic event. This conclusion is based on a study of geologic contact relationships. The volcanic products of the Belfond domes have been dated at 20,900 to 34,200 years by scientists from the U.K., which is geologically very young. The Aquater geologists also concluded that the Belfond domes represent the youngest activity within the Qualibou caldera, and therefore there is a consensus among the various groups that have worked in the area. Clearly, the Belfond dome area should be given a high priority in the selection of future drilling sites.

Although objective "b", the location of structural permeability, is discussed at length in the Los Alamos report, the discussion is difficult to follow in detail because of the small scales of the geologic map and cross-sections and because the map and sections are not only presented at

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different scales, but in different scale units. The bar scale of the geologic map is in the metric system and although the fractional scale is stated to be 1:25,000, it is actually about 1:64,000, probably because of reduction of the original drawing to page size. The vertical scale of the sections, given in feet, is calculated to be 1:50,000. It appears that the horizontal scale of the sections is equal to the vertical scale, although this is not stated.

Because of the wide variation in both subsurface temperatures and distribution of permeability in holes 1 through 7, the UK workers concluded that production in the Sulphur Springs area is structurally controlled by faulting. The Los Alamos workers agree with this interpretation, but because of the small scale of the maps and sections, it is not clear what fault is responsible for the Sulphur Valley springs. The location of the Sulphur Valley springs is not clearly shown on the geologic map, but if it is assumed that they are near wells 3 through 7, then, according to the map, the springs are on the surface trace of the regional NE-trending fault that passes through Soufrier Bay. If this is the Los Alamos interpretation, then why are the subsurface temperatures in hole #1, which is located next to this fault, so low? In section B-B', the regional fault in Sulphur Springs valley is not shown, and the closest inner caldera fault reaches the surface about 1,400 feet SW of Sulphur Springs valley. In examining the map and sections, therefore, the question arises; what fault, if any, is controlling the location of the major thermal springs in the area? To resolve this question, more detailed cross-sections should be drawn through the Sulphur Valley area and the sections should incorporate as much information as possible from the wells, including stratigraphy, temperature distribution and the location of steam entries. From detailed sections such as these, it may be possible to define the location and geometry of the fault responsible for the main display of surface thermal activity in the caldera.

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Both Los Alamos and Aquater approached the question of permeability primarily from the point of view of finding fault (structural) permeability. It is our experience, however, from work in similar volcanic environments, that stratigraphic permeability, related to specific aquifers within the volcanic sequence, can be as important as structural permeability for providing producible reservoirs. Although both groups have made significant progress in defining the stratigraphic succession in the area of interest, neither has defined the hydrogeologic characteristics of the volcanic units, with particular reference to identifying possible stratigraphic reservoirs. For example, study of the distribution of springs on the island might indicate whether the local basalt unit has sufficient permeability to form a reservoir. If so, exploration holes should be planned to penetrate several hundred feet of basalt. If not, the holes could be terminated at the base of the overlying andesite.

2.2 Geochemical Studies

The objectives of geochemical studies in geothermal exploration are:

a. to assist in defining a hydrologic model of the geothermal system by interpreting the chemistry of surface and subsurface water samples; and

b. to estimate reservoir temperature by using hydrochemical and gas geothermometers.

Based on their geochemical studies, both Aquater and LANL agree that hot springs within the Qualibou caldera are shallow meteoric water heated by steam condensate and by conduction, and not fed directly by a deep thermal fluid. The two organizations, however, have proposed different models to explain the observed hydrochemistry of these springs.

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Future exploration drilling strategies will depend on which of these models is accepted.

Aquater has concluded that a 200 to 220°C thermal system underlies most of the caldera. This system is described as a source of steam which heats overlying groundwater, but whether there is a one- or two-phase zone, and whether a brine layer is present, is not stated. If this model is correct, sufficiently high temperatures for geothermal production can be found by drilling anywhere on the caldera floor.

LANL, on the other hand, envisions a three layer geothermal system: an upper condensation zone; an intermediate vapor or two-phase zone; and a lower (boiling) brine zone. Upflow of the deep brine may occur in one or more locations central to the caldera, but most probably this deep upflow is restricted to the vicinity of Sulphur Springs and/or the Belfond dome area. Deep flow of this brine to the northern caldera wall is possible, but not positively indicated by any available evidence. Boiling of this brine at about 250°C or higher produces the steam which, in turn, condenses into the overlying shallow groundwater. The groundwater then flows horizontally down hydrologic gradients to outlying thermal spring sites at caldera boundaries to the north, northeast and possibly to the southwest. If this model is correct, exploration drilling, at least initially, should be limited to the area of Sulphur Springs and the Belfond domes.

Although the chemistry of the thermal springs can be interpreted to support either the Aquater or LANL models, we favor the LANL model because it is more consistent with the characteristics of thermal systems we have examined is similar volcanic settings. Therefore, we recommend that initial exploration drilling be restricted to the Sulphur Springs and/or Belfond dome area.

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Both Aquater and LANL use gas geothermometers to estimate deep reservoir temperature. Using the H_2/CH_4 thermometer, Aquater estimates a temperature of 350°C for a "deep" system, of unknown actual depth or areal extent, and 220°C for a shallower system underlying the entire caldera. LANL, using the gas thermometer developed by D'Amore and Panichi, estimate the deep brine temperature at 280°C. A large oxygen isotope "shift" and high B/Cl ratios qualitatively support these high temperature estimates for the deep system, and in light of the fact that the thermal waters are associated with a young volcanic system, we find these temperature estimates credible.

Samples of brine obtained from well No. 4 have an unusual composition which indicates that the fluid probably formed by interaction of sea water with young volcanic rocks, but has been strongly affected by processes of evaporation and mixing. Traditional chemical geothermometers applied to the brine give temperature estimates of no more than 180°C, which is 40°C less than the highest temperature observed in the same well. Reasons for this are uncertain, as are the level and temperature of the production zone. However, the characteristics of the brine and of the well suggest that there may exist a very low water/rock ratio in the brine zone which was produced, and the samples may not represent the deep thermal system.

Additional geochemical work is not necessary to support deep drilling recommendations, but should be carried out as part of long-term monitoring of the system. When new wells are drilled in the area, it will be particularly important to sample fluids for stable isotope determinations and gas analyses, as well as major element chemistry. Chemical and isotope data from new wells should be integrated into the existing data base in a uniform format. Although it does not seem necessary at this time to start organizing the existing data, this task should be undertaken as

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part of the reporting and analysis of chemical data from the first deep exploration hole.

2.3 Geophysical Studies

Three separate geophysical interpretations were reviewed: gravity by Aquater, audiomagnetotelluric (AMT) by Aquater, and dipole-diple resistivity by LANL. All these interpretations are based on field surveys which appear competently executed, but fail to integrate their conclusions with the results and interpretations of earlier workers. Our comments on the results of each of the three surveys are given below.

2.3.1 Gravity.

Aquater's discussion of field procedures and data reduction methods is good and provides confidence in the maps they produce. Although other workers may choose different reduction densities or regional field, the authors' choices are resonable and yield Bouguer and residual gravity maps which form a solid basis for interpretation.

The interpretation is limited by a lack of field data on rock densities. Well density logs, drill cuttings, and surface sampling would provide some basis for correlating gravity with geology. For example, results from the "Nettleton profiling" data could have been improved had the differences in rock types, and therefore densities, under each profile been recognized.

The gravity interpretation is essentially non-geologic. The placement of a "heavy plate" does not appear to be constrained by surface geology or downhole geologic information. The one concession to geology ("We assume that the heavy plate described is due to a lava flows (sic) body above the magma chamber.") does little to further the geothermal

model. Although lows are generally stated to develop from "fissuration," no attempt has been made to correlate the geologic cross section with mapped geologic units.

Aquater places no particular significance on the dominant local gravity low in the Belfond area. It would be easy to model possible sources of such a circular anomaly to provide testable hypotheses (e.g. modeled as a hot, plug-shaped dacite intrusion with its surface exposed and base within 2 km of the surface). A simple calculation also demonstrates that steam-filled rather than water-filled pores would create insufficient density contrast to cause the local low. Such geologic constraints assist in making a model which fits all available data.

Without better understanding of rock types involved, we do not agree that gravity reflects permeability to the degree suggested. Fracture permeability, so commonly dominant in geothermal reservoirs, frequently is greatest in competent, relatively dense, rock.

2.3.2 AMT Resistivity.

The report on Aquater's AMT survey is difficult to follow due to poor English and/or typographical errors. More important, the survey's depth of penetration is so shallow (500-1,000m) as to have limited usefulness in defining a reservoir. Combined with the sparsity of data from within the caldera, this survey contributes little to a model of the geothermal system.

Aquater properly points out the difficulties of using one-dimensional inversions of AMT soundings in areas of severe lateral variations. Nevertheless, their cross-sections merely piece together individual one-dimensional inversions with generous use of vertical "AMT discontinuities" between stations.

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Although the cross-sections indicate some general surface geomorphic features, little attempt is made to relate observed resistivities to petrologic properties of the features. Use of well data and other petrologic analyses would have assisted in relating resistivity structure to geologic structure.

2.3.3 Dipole-Dipole Resistivity.

The LANL report describes field procedures adequately and the survey results are believable. Once again, the weakness lies in the interpretation and integration with previous work.

Presentation of the results in pseudosection form, while standard practice, often misleads the casual reader. This is especially true in areas of large lateral resistivity variation because resistivity features portrayed at depth in a pseudosection can be strongly influenced by near-surface rock properties. The interpretation should reflect these uncertainties.

LANL's study is presented in isolation. Considerable previous work bears on the interpretation of this survey, most important of which are the drilling results themselves. Even if electric logs are not available, estimates of resistivity could be made from the lithology descriptions.

The relation of LANL's results to those of the previous IGS dipole-dipole survey should be presented. For instance, Williamson and Wright[1] (1978) also report an apparent resistivity high below Sulphur Springs, but

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1 Williamson, K.H., and Wright, E.P., 1978, St. Lucia Geothermal Project, GRC Transactions, v.2, p.731-733.

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concluded from computer modeling studies that "the apparent high resistivity zone at depth was probably due to near-surface lateral variations in resistivity." We support this conclusion.

LANL's speculations, correlating resistivity lows with a "large thermal reservoir" and resistivity highs at depth with a vapor-dominated reservoir may provide useful hypotheses to test, but are not conclusive. The first tests should come from data already available, correlations with accessible surface rocks and with previous drilling results. If, in fact, the model still fits, subsequent drilling at proposed holes #1 and #2 becomes the next logical test. A hole at the proposed site #1 also would test the source of the gravity low. At site #2, we propose an alternative hypothesis, that the anomalous body at depth is a silicic plug probably having low permeability.

Some considerations which might be discussed in interpreting the psuedosection include: (a) what is the relation of ground water depth to the near-surface observed apparent resistivities?; (b) how do near-surface resistivity boundaries relate to mapped lithologic contacts or other observable properties?; (c) if the deep high resistivity target is a steam zone, why is it not surrounded by a hot saturated zone of very low resistivity. Although a "dry steam zone" is hypothesized to be characterized by high resistivity, to our knowledge, no clear examples of this have been demonstrated in geothermal systems with proven steam zones.

Because of the proven value of resisitivity data in other geothermal prospect areas, and because so much resistivity data have been gathered over the Qualibou caldera, we recommend that a more concerted effort be made to interpret the results of these surveys. This interpretation effort should include computer modeling of both the UK and LANL dipole-dipole surveys, and incorporation of these data with the AMT data. The final interpretation should include consideration of the proposed hydrologic model, and particularly, the data resulting from past drilling.

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3. TECHNICAL REVIEW OF ENGINEERING INVESTIGATIONS AND COST ESTIMATES

This section summarizes the results of a brief technial review of a report entitiled "Evaluation of St. Lucia Geothermal Resource - Engineering Investigation and Cost Estimate" prepared by the Los Alamos National Laboratory (LANL). Gibbs & Hill's review was completed under the direction of Dr. James McNitt of GeothermEx in support of their contract with the U.S. State Department Agency for International Development. This summary of Gibbs & Hill's findings and recommendations is divided into two major sections: Geothermal Electric Power Production and Industrial Applications.

3.1 Geothermal Electric Power Producion

The LANL report proposes 2.5 MW modular units as the base case for geothermal development. Larger units should be considered for the development scenario due to economies of scale. A typical geothermal well from a hydrothermal resource will supply sufficient steam for 5 MW of power production. A 5 MW unit should be considered as a realistic size for development due to the higher unit costs of a smaller power plant. Two 5 MW (net) units would satisfy the base load electrical consumption for St. Lucia until 1990. A detailed economic study is required to determine the optimum quantity of the peak load power that should be generated from geothermal facilities. The existing 16 MW of diesel generating capacity on the island should be maintained for peak power production and for reserve capacity for scheduled and forced outages of the geothermal units.

The capital cost of a wellhead geothermal power plant is underestimated in the LANL report. The LANL report cites an installed cost of $1000/kW including hydrogen sulfide removal. Recent conceptual designs and detailed cost estimates by Gibbs & Hill have shown that the installed

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capital cost of a modular 5 MW wellhead generator is in the range of $1,400 to $1,700 per kW (1984 $'s). However, the overall costs of the geothermal wells provided in the LANL report are indeed quite conservative as stated. Thus, it appears that the overall costs of the geothermal power development stated in the LANL report are realistic when the low power plant costs are combined with the high well costs.

The LANL report incorrectly concludes that conventional induced draft cooling towers should be avoided due to the lack of make-up water and the high parasitic cooling tower fan loads in the St. Lucia climate. In practice, geothermal steam condensate can be used as the sole source of make-up cooling water, as is the case for all geothermal units at The Geysers in California. Also, the design conditions for an evaporative cooling tower on St. Lucia are not as severe or restrictive as one might believe. According to the ASHRAE Handbook of Fundamentals, the 5% design wet bulb temperature for the neighboring island of Martinique is 80°F. The design wet bulb for St. Lucia can be expected to be similar and is not so unusually high as to result in unacceptably large cooling tower fan loads. This design temperature is the same as in the Philippines, where all 18 geothermal power plants incorporate evaporative cooling towers. Induced draft fans are also used successfully in Hawaii on the 3 MW plant near Hilo.

It is highly likely that the use of conventional evaporative cooling towers would result in a lower cost of power than the use of ocean cooling. The base case 2.5 MW power plant presented by LANL utilizes ocean cooling with an underwater pipeline approximately one-mile long connected to above ground piping spanning an additional mile in length. It is difficult to imagine that the extremely high cost of this cooling water pipeline is justifiable for a unit of this size. Perhaps if a power plant were located at the shoreline and cold ocean water were available at lesser

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depth, ocean cooling would be justified. Also of interest is the fact that though the LANL base case design incorporated ocean cooling, the cold ocean water was not utilized to its full advantage. LANL assumed 60°F cooling water was available, yet, the plant was designed for a condensing temperature of 115°F.

The LANL report proposed hydrogen sulfide removal upstream of the turbine. There are no commercially available technologies for upstream hydrogen sulfide removal. A prototype technology should probably not be proposed for the first unit on St. Lucia.

3.2 Industrial Applications

LANL correctly concludes that geothermally supplied electric-intensive industries do not appear feasible for development on St. Lucia. The anticipated cost of geothermal electric power is not sufficiently low to be competitive with the cost of electricity available elsewhere.

The cost of thermal energy for direct use geothermal projects is highly dependent on the proximity of the end user to the production wellheads. Due to the high cost of piping and excessive heat losses, it is not economical to transport hot brine over long distances. Thus, it can safely be concluded that direct use of geothermal projects will make sense for St. Lucia only if the geothermal wellheads are close to an accessible site for building a factory.

LANL has identified ten industries for potential development of direct use geothermal applications. Six of these industries appear worthy of further investigation to assess the economics of geothermal heat utilization. These six industries are: (1) coconut oil production; (2) timber drying; (3) concrete block production; (4) beer production; (5)

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banana chip production; and (6) tourist and other commercial hot water applications. The production of alcohol/gasahol from sugar cane has questionable economics due to the very low production rates. (It could support a sugar mill that processed only 32,153 tons of sugar cane and an alcohol distillery that produced only 483,200 gallons of alcohol per year.) Dry ice production requires that new technology be developed for separating the carbon dioxide from other gaseous constituents. Fresh water production is a costly process that cannot be competitive with natural water sources. The production of aluminum from bauxite is an unlikely industry for St. Lucia since both bauxite and sodium hydroxide must be imported.

The LANL report proposes to use geothermal fluids as primary heat supply to Soufriere with a return reinjection temperature of 48°C (119°F). Experience indicates that higher temperature (482°F) geothermal fluids can cause major scaling problems when the temperature is dropped to this extreme.

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4. TECHNICAL REVIEW OF MACROECONOMIC MODELS

LANL discusses two separate macroeconomic models. Part I of the report discusses the first, the Macroeconometric Model, which forecasts the gross domestic product (GDP or GNP, sic) for the period 1983-1985. Besides the limited value of projection for this period of time, the presentation fails to provide a credible discussion of reliability and uncertainty in the estimates. In fact, the lack of reliability seems demonstrated by the self-test of trying to predict 1982 from the previous data set. Whereas the GDP went up about $3 million, the model seems to have predicted a decrease of about $5.7 million. The authors' approach of taking this discrepancy as a correction factor of $8.7 million, which they then apply to future years, has not been justified.

In many of the contributary regression equations, dummy variables (fudge factors) are introduced to accommodate one or two years which would otherwise decrease the correlation coefficient. Without any other justification given for these factors, one must interpret them as adjustments for essentially non-recurring events, which disturb a normal correlation. It thus seems unreasonable to extrapolate these factors as continuing constants simply because that factor was used in a previous year, as has been done. At a minimum, such a procedure must be given some explanation and justification.

The model predictions also rely upon simple extrapolation of about 16 input (exogenous) variables. Since these extrapolations determine the outcome of the model equations, some variable by variable justification is necessary to lend credibility. Whereas some variables, like population growth, may be easily justified, others are not at all clear. For instance, the banana maturity cycle is given values 1,2,3,4,5,1,2,3,4,5, 1,2,3 throughout the

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correlation period -- it is not at all clear why the next three years are 4,5,4 (p.39).

Obtuse references to banana cycles and "the hurricane-caused drop" without explanation do little to enlighten the reader. If these are major economic factors, they deserve some discussion. How likely are hurricanes, which could throw off all linear predictions?

Although various statistical functions are displayed in the pages of computer printout, they seem to be ignored, both in terms of explaining criteria used and in carrying over individual correlative uncertainties and sensitivities to the combined conclusions. Without this the reader is given no sense of predictive reliability.

The text refers to the predictive equations derived, and they can be derived by the reader from the contributary regressions, but explicit listing would save the reader some effort. The final predicting equations and logical order of calculation should be given to better explain the process.

Readability of the report is severely hindered by the use of computer variable names which, if defined at all, are defined in scattered tables. Definitions of DST78 or REGXPT could not be found. It would greatly help to not rely on computers to present the correlation results, which could easily be typed using real words instead of computer code. Where variable names are used, definitions should be placed in a master glossary.

All in all, the logic of the procedure is poorly explained and, consequently, the careful reader is left with little confidence in the conclusions -- as moderate as they are. Some recognition and quantification of uncertainty could aid in the model's credibility.

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Part II deals with a Nonlinear Optimizing Model. Although we find the way this model relates the interdependence of factors more credible, the exposition suffers from the same lack of clarity as Part I. A discussion of uncertainties, sensitivies, logical steps, and the bases for assumptions is required to make this section more credible. A clear list of variable names and a careful editing (e.g. in eq. 9, shouldn't "=" be "+"?), would be helpful.