**CONSULTATION FOR THE H₂S
AND METEOROLOGICAL
MONITORING PROGRAM
OF THE ENTE NAZIONALE
PER L'ENERGIA ELETTRICA
(ENEL)**

Final Report

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I OVERVIEW

A. Objectives of the Contract

The objective of the contract was to provide expertise and special knowledge regarding the monitoring of air quality in the vicinity of geothermal development in vapor-dominated fields. In particular, its object was to assist the DOE and Ente Nazionale per l'Energia Elettrica (ENEL) in their joint plan to characterize the distribution of H_2S in the vicinity of the Larderello-Castelnuovo geothermal field so that comparisons could be made with similar data from the California Geysers area.

SRI had relevant experience in monitoring H_2S by virtue of a contract with Pacific Gas and Electric Company (PG&E) and their partners. SRI had installed and was operating an observational network to obtain data on the distribution and concentration of H_2S around The Geysers area and was also collecting meteorological data. These data were analyzed to provide a determination of the atmospheric distribution and concentrations of H_2S in that area. Based on this experience, we proceeded to assist ENEL in setting up a comparable monitoring program in Italy and in analyzing the results. It was also hoped that ENEL's monitoring activities would serve to enhance our knowledge on the subject.

B. Abbreviated Summary of Accomplishments

ENEL has benefited from SRI's experience in planning, operating, and analyzing the results from the H_2S and meteorological monitoring network in The Geysers area. By means of three visits of SRI personnel to ENEL, we were able to assist them in setting up their monitoring program. These visits were supplemented with reports on problems, progress, and results associated with SRI's Geysers program.

C. Topics of Future Information Exchange

As discussed in Section V, ENEL could benefit from additional experience and studies concerning the Geysers. These studies would be particularly useful in evaluating sites for new ENEL power plants and for additional phases in ENEL's H_2S and meteorological monitoring program.

In addition to ENEL benefitting from our experience, we suggest some studies concerning the Larderello area that would be of significant value to the DOE. The first of these studies concerns the identification of adverse biological effects, including those to human health.

The second study concerns the analysis of the ENEL H₂S and meteorological data base to answer fundamental questions on dispersion in complex terrain. The analysis could be highly beneficial in providing the DOE with further guidance on siting geothermal facilities (power plants). As described later, the Larderello scenario is unique and would result in a data base unparalleled by any currently available in the United States.

To accomplish the above objectives, future information exchanges between the appropriate U.S. organizations and ENEL would be necessary.

II INTRODUCTION

A. Background

Figures 1 and 2 illustrate the geographic area of interest, location of power plants, and monitoring sites. Briefly, four power station complexes are in operation--three along the Possera Valley and one to the south near Castelnuovo on the ridge between this valley and that of the Pavone. The most northerly of the power stations along the Possera Valley (Gabbro) is about 6 km from the most southerly station at Castelnuovo. The latter station is at a height of approximately 590 m. The two middle-level stations (II and III) near the village of Larderello lie at about 460 m, and Gabbro is at 370 m. Habitation is centered in Castelnuovo di val di Cecina in the saddle connecting the Possera and Pavone Valleys just south of the Castelnuovo power station; at Larderello, which lies in the valley below Stations II and III; Montecerboli, which stands on the western side of the Possera Valley between Larderello and the Gabbro station; and finally, S. Dalmazio, which lies to the east of the saddle between the two valleys just north of Gabbro. Both valleys are fairly broad and regular, with the separating ridge extending some 200 to 300 m above the valley bottoms. Within the broader valley, streams have cut quite deep and narrow courses in some places, particularly, in the case of the Possera, below Larderello village.

A brief review of available meteorological data* for the Larderello site shows a typical sequence of variable cloudy and rainy weather in winter with fog conditions. Winds are mainly N or S, as would be expected from the terrain. Anticyclonic conditions in summer (August) produce several days of calm, hot weather.

Emissions of H_2S are similar to those at the Geysers, although the steam at Larderello contains a higher proportion of noncondensable gas. Certainly the concentrations are well above the odor threshold (~ 30 ppb) in many parts of the area, even in good ventilation conditions. On a quiet night, a Colortec card indicated an average of 40 ppb for 1800-0800 at the Albergo la Perla, just above Station III (the more northerly of the Larderello complexes). On the following night and subsequent day, however, only < 5 ppb were indicated from 0800-0800. A card worn as a personal monitor throughout the area for a period of 24 hours

*Annali Idrologici, Bacini del'Arno, Magra e Fiora, 1971: Ministero dei Lavori Pubblici, Roma, 1974, and local records.

FIGURE 1 MAP OF THE LARDERELLO AREA SHOWING POWER PLANTS AND METEOROLOGICAL MONITORING STATIONS

FIGURE 2 MAP OF ITALY SHOWING THE RELATIVE LOCATION OF THE LARDERELLO GEOTHERMAL REGION

corresponding to the second period noted above indicated ~ 5 ppb. On the other hand, concentrations were noticeably very strong along the road near the Gabbro Station.

B. SRI's Role in Exchanging Information

ENEL decided to establish an H₂S and meteorological monitoring program to quantify H₂S concentrations throughout the area. SRI's role involved exchanging information on experience gained in a similar program for the Geysers area, providing consultation to ENEL in the establishment of their sampling program, and soliciting any available information from ENEL concerning the definition of H₂S concentrations and any resulting effects (e.g., health).

Most of the information exchange was accomplished in three visits to ENEL over a period of approximately three years. The first visit to Landerello was made by Mr. Ronald T.H. Collis with the objective of providing advice on the conduct of a preliminary survey of H₂S incidence in the area and the initial aspects of an extended monitoring program. This advice covered consultation on meteorological and terrain factors, the type of instrumentation, and measurements. Mr. Leonard A. Cavanagh made the second visit to the site to review preliminary data and to advise ENEL on the implementation of an extended monitoring program and on the form of data acquisition and presentation. The final visit, by Dr. Ronald E. Ruff, was made to advise and assist ENEL in the analysis of their data and their technique of reporting results.

In addition to the trips outlined above, correspondence on technical issues was exchanged over the period of performance. This included reviewing reports from ENEL and supplying ENEL with reports on relevant SRI projects, with special emphasis on the Geysers project.

III REVIEW OF SRI VISITS TO ENEL AND LARDERELLO

A. Trip 1, 19 to 25 November (1976)

Ronald T.H. Collis visited Pisa and Larderello, 19-25 November 1976 to initiate liaison under project EEA-5/1 (Hydrogen Sulfide and Meteorological Monitoring).

In Pisa he met:

Dr. P. Ceron, Director	}	Centro Richerche
Dr. R. Cataldi		Geotermiche (CRG),
Dr. P. Muffler		ENEL, Pisa
Dr. G.C. Stefani		Geologist U.S.G.S.
		Servizio Minerario,
		ENEL, Florence

In Larderello he met:

Dr. G.C. Ferrara, Director	}	Laboratorio Geotermico,
Dr. R. Bertrami		CRG, ENEL, Pisa
Engineer G. Allegrini, Manager		Servizio Minerario,
Dr. L. Ciampolini		ENEL, Larderello

In addition to extensive discussions, he toured the Larderello site and vicinity and was shown the location of proposed meteorological monitoring stations and where tests for H₂S were to be made. With the aid of slides and other material, Collis described the SRI monitoring network being operated for PG&E and their partners at the Geysers area in California. He also described the tracer gas technique of tracking air movements, assessing source strengths, and identifying individual air trajectories from multiple sources. The use of Colortec H₂S detector cards was also demonstrated.

B. Trip 2, 19 to 23 September (1977)

Mr. Leonard A. Cavanagh visited Pisa and Larderello, Italy, 19 to 23 September 1977 to continue liaison.

On 19 September, Cavanagh attended a preliminary briefing at ENEL-Pisa, proceeded to another briefing at Lardareello, and returned to Pisa on 21 September, to attend a Project EEA-5/1 meeting.

At the preliminary briefing in Pisa on 19 September, he met with Dr. P. Ceron, Director, and Dr. R. Cataldi. Dr. R. Bertrami of the Laboratorio Geotermico, CRG, accompanied Cavanagh from Pisa to Larderello and was his primary contact during this trip.

At the briefing session in Lardarello (19 September) he met with the following ENEL personnel: Dr. G.C. Stefani, Dr. G.C. Ferrara, Dr. R. Bertrami, Dr. L. Viviani, and Engineer G. Allegrini.

The Project EEA-5/1 meeting in Pisa on 21 September 1977 was attended by Drs. Cataldi, Stefani, Ferrara, Bertrami, Viviani, and Allegrini of ENEL. In addition to the ENEL representatives listed above, the meeting was attended by Dr. Scandiffio of ENEL Laboratorio Geotermico CRG, Dr. P. Muffler of USGS, and Mr. R.R. Loose of DOE (then ERDA).

In addition to extensive discussions, Cavanagh toured the Lardarello site, the proposed meteorological monitoring sites, and the Laboratorio Geotermico, CRG, at Castelnuovo. He described SRI's measurement program at the Geysers, discussed instrumentation and analytical techniques, and inspected the ENEL mobile monitoring van. With Dr. Bertrami, he conducted preliminary comparisons between the ENEL permeation tube calibrator and a permeation tube whose permeation rate had been verified by SRI International. Copies of analytical procedures were left with Dr. Bertrami and arrangements were made to send further information.

C. Trip 3, 4 to 8 June (1979)

Dr. Ronald E. Ruff visited Florence, Pisa, and Lardarello to continue liaison with ENEL and to exchange ideas with the new DOE Project Officer, Dr. Robert R. Reeber.

On the first morning, Ruff met with SRI's principal correspondent from ENEL, Dr. G.C. Stefani, in Florence. Later in the day, Ruff briefly met in Pisa with Dr. P. Ceron (Director, Centro Ricerche Geotermiche, ENEL) and Mr. R. Corsi (ENEL). Later, Ruff and Reeber met privately to exchange ideas, discuss project status, and identify the most useful research areas for future discussion and reporting.

Along with Dr. Reeber and Mr. Corsi, Ruff travelled to Lardarello. Upon arrival, they attended an introductory meeting chaired by Dr. G.C. Ferrara, Director, Laboratorio Geotermico, CRG. After initial discussion, it was decided to break into two groups, one of which focused on air quality. The air quality group consisted of: Dr. G.C. Stefani (ENEL), Dr. R. Bertrami (ENEL), Engineer Pagliari (ENEL), Engineer Parrini (ENEL), and Dr. R. Ruff (SRI International). For the remainder of the morning, they discussed the ENEL monitoring and modeling program. Monitoring results were made available for discussion but had not been approved for release. Hence, no actual comparisons with Geysers data were made. However, comparisons in the methods of analyses were made, including types of air quality models that might be applicable. (Details are given later). In the afternoon, monitoring sites were toured and considerable time was spent in familiarizing Ruff with the local topography.

On the next day, the group toured ENEL Larderello, including the ENEL museum, a power plant, a drilling rig, and one of the few remaining natural fumaroles in the area. Later, Ruff met with Dr. Bertrami who provided him with details on the current ENEL monitoring program (Phase A) and future plans (Phase B). Dr. Bertrami also provided Ruff with a written draft of the Phase A results, together with topographical maps showing previous and current monitoring sites. Ideas were exchanged on future monitoring activities. Based on SRI's experience in the Geysers, a number of recommendations were made and discussed.

A final visit was made by Ruff to the Centro Ricerche Geotermiche to present his overall view on ENEL's monitoring program. The Director (Dr. Ceron) was not able to keep the appointment so Ruff spoke to Mr. Corsi instead.

IV AIR QUALITY (H_2S) COMPARISON BETWEEN ITALIAN AND AMERICAN GEOTHERMAL PLANTS

A. Basic Concepts

The objective of the ENEL monitoring program is to characterize pollution conditions as they exist in the vicinity of the Larderello geothermal area. This parallels the overall objective of the monitoring program in the Geysers area. However, there are many differences. Firstly, the areas of concern differ, since at Larderello the principal habitations lie in and adjacent to the area of geothermal operations. At the Geysers, the main operations are in remote areas (although planned developments will lie closer to the main populated areas of Cobb Valley to the east). Secondly, in California, regulations regarding the permissible level of H_2S concentration in the ambient atmosphere are already in effect (0.03 ppm averaged over 1 hr, although the question of where measurements of such concentrations are to be made for legal effect is not defined). In Italy, regulations have not yet been promulgated but are expected. Again, the intention of the Geysers program is to provide a basis for observing changes in the current situation, both with regard to the installation of emission control techniques and to the start-up of new plants. It is also expected to provide the basis for mathematical simulation modeling for the prediction of air quality as a result of such changes. The Larderello operations are essentially stable and the field is not under active development. In addition, the political aspects of environmental control are different in the two cases. In California, federal, state, and particularly local government agencies are involved with the regulation of corporations operating the field (PG&E and their partners). In Italy, ENEL is a national agency and different supervisory arrangements apply. Finally, of course, although there are certain similarities of topography and climate, the physical circumstances are by no means identical.

All these factors are significant in determining how closely the monitoring program in the Larderello area should follow the Geysers approach.

B. Current H_2S Levels

A quantitative comparison between H_2S concentrations in Larderello and in the Geysers cannot be made at this time because monitoring results have not been released by ENEL. Hence, our comparison here is made in subjective terms.

In terms of H_2S concentrations, there are two different degrees of adverse impacts that must be considered. The smaller of the two is the

"nuisance" impact associated with the "rotten eggs" odor resulting from low concentrations of H_2S . The odor threshold varies from individual to individual and corresponds to an H_2S concentration in the range of 0.01 to 0.03 ppm. The more significant impact would involve some sort of biological damage to humans and other species (e.g., plants). However, the magnitude of H_2S concentrations to cause such impacts has not been sufficiently defined. Research in this later area has proceeded on a low priority basis.

The odor impact is of concern to the population centers near to the Geysers. As described in Appendix C, H_2S concentrations conducive to odor detection do occur, although infrequently in populated areas. In general, such odors are not acceptable and the State of California has established a standard so that the causes of such odors can be regulated.

In Larderello, the odors occur more often in the populated areas than they do in the Geysers. A primary reason for this is the proximity and meteorological coupling of the Larderello power plants to the populated areas. In contrast to the Geysers, the Larderello power plants are closer to the towns and located in the same valley as these towns and, thus, share the same air mass. As a result, the odors are more a way of life in the Italian towns and, at first glance, are accepted as such by the people who chose to live there.

Other than the odor impact, the existence of more serious effects remain unknown for both locales. In Larderello, the ambient H_2S concentrations have not been adequately characterized as of yet. Even having such characterizations does not enable one to quantify serious biological effects because the cause-effect relationship is not known.

C. Effect of Future Growth

Future geothermal growth is predicted by both ENEL and the major utility in the Geysers (PG&E). However, there is a major difference. ENEL's growth probably will be in new (Italian) geographical areas quite distant from Larderello (e.g., 50 km away). Because of this distance, there would be little contribution of H_2S emitted in one geothermal area to the air mass in the other area. The net result is that further geothermal development should not significantly worsen the situation in the vicinity of Larderello.

On the other hand, the Geysers is expanding and some new (or planned) geothermal plants and wells are closer to the populated areas to the east. (On Figure C-1 note the location of planned unit 13 with respect to Anderson Springs). Hence, without control measures, the ambient H_2S problem would certainly worsen as geothermal power production increases. However, control measures are being taken such that the populated areas are protected against exceedances of the standard of 0.03 ppm. The effectiveness of such measures remains to be quantified.

V RECOMMENDATIONS

A. Italian Studies of Interest to the United States

In terms of air quality research, specifically with regard to H_2S , the ENEL program has been of general scientific interest. Because there has been no H_2S regulation in Italy, the ENEL research has lagged behind that of the United States. In fact, the ENEL program is just now beginning to generate air quality and meteorological results.

There are air quality topics unique to Larderello that are of interest and potentially would have high value. The documentation of health and biological differences between the geothermal production towns (Larderello and Castelnuovo) and similar Italian locales without geothermal production would be of extremely high value. Larderello is unique because its population has been exposed to high H_2S concentrations for decades. The United States has no similar situation. Hence, a careful study of such health and biological differences could lead to the establishment of some subjective and possibly quantitative cause-effect relationships.

The ENEL meteorological and H_2S data base when completed could be highly beneficial to the United States. While certain aspects are unique to the specific locale, it may be useful in enhancing our understanding of certain air quality problems. In particular, it may serve as a basis to help evaluate siting of future United States facilities. The Larderello locale is similar in complexity to areas within the United States where known geothermal resource areas have been identified. Analysis of the ENEL data base would help us to formulate the dispersal of geothermal plumes emitted in a broad valley. Meteorological conditions that lead to "channeling," "stagnation," and "cross ridge" transport (and mixing into another valley's air mass) could be analyzed. (The location of the plants in the Possera Valley and possible transport of the pollutants to the Pavone Valley is of interest here.)

B. United States Studies of Potential Interest to the Italians

Having been the first organization to monitor extensively and continuously the ambient H_2S concentrations in the vicinity of a geothermal power complex, SRI has been uniquely able to advise the Italians on such topics as siting monitors, selecting equipment, quality assurance, and data analysis (and presentation). Hopefully, we have been able to convey enough information about our successes and failures such that ENEL has benefited from our experience.

In January of 1980, SRI completed its H₂S monitoring program in the Geysers after three years of operation. However, special studies continue in support of establishing new facilities in the Geysers. These studies are usually site specific and attempt to estimate the impact of new H₂S sources (e.g., power plants, wells) or control of existing sources. The information collected should be of value to ENEL in their siting of new facilities.

If ENEL is to go beyond Phases A and B of their monitoring program, they could continue to benefit from the extensive monitoring and analysis performed in the Geysers area. Results from these studies would prove useful in helping them plan and execute additional phases of their monitoring program.

Appendix A

THE ENEL H₂S AND METEOROLOGICAL
MONITORING PROGRAM

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The ENEL program has to date consisted of two phases. Phase A concerned a preliminary quantification of H₂S throughout the geothermal area using a mobile monitoring van. Phase B is concerned with the meteorological characterization of the area. Data from this second phase will be used in concert with an air quality model to further define the spatial distribution of H₂S. Additional monitoring phases are being considered but have not been fully defined as yet.

1. Phase A

Phase A of the ENEL monitoring program has been completed. A draft report has been written by Dr. Bertrami but has not yet been released by ENEL officials.

The Phase A program consisted of H₂S monitoring by the ENEL van with a total sulfur analyzer using a Flame Photometric Detector (FPD). Complementary meteorological measurements were taken at other locations. In all, 643 H₂S measurements were taken at 42 sampling points over the study area. Meteorological measurements--winds and temperatures (including temperature gradient)--were taken at about 90 separate times using portable instruments. (Temperature gradients were computed using a temperature difference between two locations differing by 100 meters in elevation).

The van was operated in geographical areas where H₂S concentrations were thought to be most influenced by the geothermal discharges. In the more remote (marginal) areas, Colortec detectors were deployed. In all, 506 measurements were taken at 24 different locations.

Results from the above analysis are currently under review. The analysis itself consists of presentation of H₂S concentrations at the different sites and categorization of H₂S concentrations according to classes of meteorological parameters. Preliminary indications are that correlations are low between H₂S and wind classes or between H₂S and temperature gradient. However, the sample sizes (number of observations) were small, and ENEL realizes that additional monitoring is required to obtain useful correlations.

The ENEL monitoring van contains a Meloy Total Sulfur Analyzer, a Meloy Permeation Tube Calibrator, a clean air supply, and a data logging system to provide a time signal and the output of the Total Sulfur Analyzer in both analog and digital (paper printout) format. A filter to remove SO_2 selectively from the sample air prior to analysis can also be switched into operation. The permeation tube calibrator uses a permeation tube containing SO_2 for calibration rather than H_2S . The use of SO_2 instead of H_2S as a calibration standard is satisfactory, though the results may be somewhat less credible. The response of the total sulfur analyzer will, however, be essentially identical for H_2S and SO_2 , and the use of SO_2 as a standard facilitates the calibration of the SO_2 filter.

Calibration of the ENEL H_2S monitor was a subject of considerable discussion between Cavanagh (SRI) and Bertrami (ENEL). It was decided to compare results between ENEL's monitoring and a calibration standard* for SRI. A preliminary comparison, made during Cavanagh's visit, indicated agreement within 10 to 14 percent which was determined to be well within experimental error. Subsequent tests conducted separately by Bertrami compared calibration results using the SO_2 permeation tube (ENEL's method) and SRI's H_2S permeation tube. Results were in good agreement (Bertrami, 1978).

2. Phase B

Phase B of the monitoring program shown in Figure 1 currently includes meteorological monitoring at five locations as follows:

- One principal station on the ridge measuring wind, humidity, barometric pressure, temperature, solar radiation, and precipitation. The objective of this station is the measurement of parameters representative of the general Larderello area (i.e., regional conditions).
- Two stations on ridges in saddles separating valleys measuring wind, temperature, and humidity. The wind instruments measure cross-ridge air movement (into or out of the valleys where the power plants are located).
- Two stations located in the valleys and measuring humidity and temperature. The temperature measurements in conjunction with those at the ridge line provide (after subtraction) an estimate of the vertical temperature gradient in the vicinity.

*A permeation tube containing H_2S with a permeation rate verified by SRI to be 150 $\mu\text{g}/\text{min}$ $\pm$ 5 percent at 30°C.

In addition to the meteorological measurements summarized above, the ENEL mobile H₂S monitoring van will be used.

ENEL plans to develop an air-quality model for the area; the five-station meteorological network will collect the necessary long-term data base. Meanwhile, ENEL is considering various types of models for application to the geothermal area.

Appendix B

SRI COMMENTS ON THE ENEL MONITORING PROGRAM

Appendix B

SRI COMMENTS ON THE ENEL MONITORING PROGRAM

1. Overview

Most of our comments are based on comparable experience gained in operating our network in The Geysers geothermal area. However, there are some differences in the objectives of air-quality studies in comparing The Geysers with Larderello. The primary difference stems from the fact that (from the standpoint of geothermal power production) The Geysers is a growing area, whereas Larderello is not. Hence, many air-quality studies conducted in The Geysers area provide basic information upon which to base a decision (viz., approval to construct a new power plant, or where to locate a power plant.) In our opinion, meteorological and air quality (e.g., H_2S) information gathered for the Larderello area serves the following purposes:

- The ambient H_2S measurements serve as a baseline upon which to evaluate air-quality trends and provide decisions (e.g., the necessity for controls).
- The meteorological data (collected in Phase B) can be used with an air-quality model to estimate the amount of control necessary to achieve a specified ambient air-quality goal. Furthermore, the approach can be used to identify which plants (or cooling towers) are most beneficial to control (in terms of effect on air quality).

Continuance of a monitoring program is necessary if ENEL is to realize the above objectives.

2. ENEL's Monitoring Program

Phase B of ENEL's program is currently underway. The five meteorological stations are collecting data. In addition, the mobile H_2S monitoring van will be available. It is assumed that the van will be used as it was previously. However, some modifications in its operation are suggested:

- H_2S permeation tubes should be used instead of SO_2 permeation tubes so that potential losses of H_2S on sample line surfaces would be similar for ambient samples and calibration gas.
- Permeation rates should be verified by wet chemical methods, which should then be compared to permeation tube weight-loss methods.

- H₂S concentrations should be continuously monitored at a few selected locations over time intervals of from two weeks to one month. The present data base lends insight in where to site the van, viz., locations of potential significant H₂S impact. However, these previous H₂S measurements do not comprise a sufficient number of samples to draw any general conclusions about the general frequency distribution at each site.
- If it is desired to compare the ENEL data with those H₂S measurements at The Geysers, data should be reduced to hourly averages (rather than 7.5-minute averages). In general, the magnitude and percentage frequency of high pollution concentrations are greater for shorter averaging times. Hence, existing data summaries for Larderello and vicinity may appear to be unduly biased toward high concentrations.
- Measurements should be conducted for a variety of meteorological conditions representing different diurnal and seasonal variations. This will require that the mobile van be deployed at each selected location, four times a year, operating at all hours of the day (and night).

Clearly, if the monitoring van is to be used in the manner described above, coverage will be limited to five to six sites--allowing for two weeks in each of four seasons, or eight weeks per site. (Five sites per year would require 40 monitoring weeks, with the remaining twelve weeks necessary for set-up, take-down, and maintenance.)

3. Modeling

As stated earlier, ENEL is now evaluating various types of models that might be applied to Larderello and the surrounding area. However, acceptable "complex terrain" models do not exist, at least as general-purpose tools. For The Geysers, we have concluded that data are not sufficient to develop and validate a complex terrain model for the entire geothermal area. The SRI report (Ruff et al., 1978)* covering two years of data analysis concluded: "No matter how well conceived any model would be for the vicinity of The Geysers, the fact remains that there are not enough validation data to verify many essential components of such a model. Hence, it is our conclusion that development of an operational air-quality model for The Geysers is not feasible until a more comprehensive data base has been assembled."

The above statement certainly holds true for the Larderello area because the data base are much more sparse than for The Geysers. Hence,

*Ruff, R.E., L.A. Cavanagh, and J.D. Carr, 1978: "1976-77 Biennial Report--Specialized Monitoring Services," Report to PG&E on Contract 5-12-75, SRI Project 4351, SRI International, Menlo Park, California (December).

development of a comprehensive model for the entire geothermal area is not a realistic goal for the near future. However, development of models with limited objectives is practical. Such limited objectives might include:

- Estimating the general locations of maximum and minimum H_2S concentrations. Assuming H_2S could be monitored at a few of these locations, one could estimate the worst concentrations. Hence, when selecting housing or business sites, models could give guidance on the most desirable locations in terms of air quality.
- Estimating relative benefits of various H_2S control measures. For instance, if high concentrations are caused by a number of sources, a model would demonstrate which sources dominate and thus are most advantageous to control.

For an expanding geothermal area, another modeling objective would be to provide information on the merits of alternative source (e.g., cooling tower) locations based on their impact on air quality.

To satisfy the limited objectives described above, we recommend that simple Gaussian-plume models be adapted to the Larderello area. Some versions of these models treat the interaction of the plume and terrain variations as a function of meteorological conditions (e.g., atmospheric stability). Non-steady-state versions of these models (i.e., Gaussian puff) may be the most applicable because they can treat stagnation conditions. One advantage of using the simple Gaussian model is that the data requirements are reasonable (i.e., achievable with a data-acquisition program comparable to ENEL's Phase B program).

4. Other Recommendations

Implicit in our recommendations is the assumption that the air-quality impact of geothermal power production will be under the scrutiny of some Italian regulatory agency, perhaps several years from now. We thus suggest that ENEL consider an additional phase to their monitoring program to add a few (say, three to six) permanent H_2S monitoring stations at fixed sites. These monitoring stations would be operated over a period of several years and provide the following benefits:

- A continuous record of H_2S concentrations, which will serve as background data for future regulatory decisions. Because the stations are at fixed locations, air-quality trends can be determined. Hence, it will be possible to quantify the effectiveness of control measures, or to relate H_2S concentrations to biological data.
- A climatological data base of H_2S concentrations, which will serve as a data base for evaluation of an air-quality model as described in the previous subsection.

The cost of a monitoring program, as outlined above, is of course dependent on the number of stations. Fixed stations do not need the amount of attention that mobile monitoring stations do. A three- to four-station network would probably require two full-time persons: one to maintain the equipment and one to reduce the data. The investment is small compared to the cost of control equipment. Also, the benefits of monitoring are significant, in that the resulting data provide an objectively derived focal point for future evaluations and decisions.

Appendix C
SUMMARY OF ENVIRONMENTAL SCENARIOS
IN THE UNITED STATES

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1. The Geysers

In late January 1976, SRI International (formerly Stanford Research Institute) undertook a study to quantitatively assess hydrogen sulfide (H_2S) concentrations in the vicinity of The Geysers, California (see Figure C-1). Data for this assessment continued to be collected in 1978 from the network of eight automatic stations that monitor pollutant concentrations and meteorological conditions in the area of interest. The data acquired provide a baseline for assessing the changes in ambient H_2S concentration caused by (1) the operation of existing power units without abatement systems, (2) the addition of new power units, (3) the addition of emission controls to existing units, and (4) the drilling of more steam wells for future facilities.

Objectives of the monitoring program included:

- Characterizing H_2S concentrations over the area of interest.
- Defining population exposure to H_2S .
- Defining meteorological conditions in the area of The Geysers.
- Defining processes affecting transport and diffusion of H_2S .
- Characterizing year-to-year trends.

Some of the conclusions are briefly summarized below.

The objectives have been met with varying degrees of success. The first two objectives were satisfied quite well because the monitoring sites are generally representative ones, and the H_2S data should be representative of the local area. The third objective was satisfied to the extent that data capture for the meteorological parameters was quite high. However, defining meteorological conditions in a much broader sense would have required measurements far beyond the scope of this monitoring program--i.e., broader measurements are needed to define adequately the governing physical processes. Nevertheless, some limited characterizations of transport and diffusion were realized.

The last objective in characterizing year-to-year trends has been realized to the extent that three years worth of data constitutes a "trend." In general, the most dramatic observations concern the valley sites (i.e., Kahm Ranch, Sawmill Flats, and Anderson Springs). In general, the number of high concentrations showed a sharp decline from 1977

FIGURE C-1 MAP OF THE CALIFORNIA GEYSERS AREA SHOWING POWER PLANT AND MONITORING NETWORK LOCATIONS

to 1978. At other locations there were only slight changes that cannot be characterized as a trend, given our current understanding of the situation.

Year-to-year trends are summarized in Figure C-2. The graphic for each station demonstrates how often the concentrations were at or above 20 ppb, 30 ppb, and 40 ppb, respectively. For three stations (1, 3, and 7), the number of occurrences in each category decrease from year to year. Stations 2 and 5 show decreases in most categories from year to year. For station 4, slight increases are seen for most categories, although the number of 20 ppb and above occurrences have stayed about the same for all three years with a peak in 1977. A pronounced 1977 peak exists for Station 6, with concentrations being reduced in 1978 to about the same as they were in 1976. Station 8, the most easterly site, shows a slight increase from year to year. However, the data capture for Station 8 was quite low (54 percent); therefore, the indicated increase may be misleading.

2. Other Areas

The Imperial Valley region (south-central California) is the only other geothermal area that has had an extensive air-monitoring program (Ermak et al., 1979). This valley has an arid climate, but due to extensive irrigation it is now an important agricultural region. At present, a geothermal power plant does not exist in this region. Hence, monitoring has been useful only in terms of providing background information on air quality.

Using fairly simple air-quality models, calculations were performed to determine allowable H_2S emission rates for the Imperial Valley. It was found that even for hot-water driven power plants (of a reasonable size) that emission controls would be necessary to meet the California ambient H_2S standard of 0.03 ppm.

The H_2S impact from potential geothermal power plants located in other areas is being analyzed under contract to several governmental agencies. These areas include Roosevelt Hot Springs (southwest central Utah), Raft River (south central Idaho), Brady Hot Springs (northern Nevada), and Desert Peak (northern Nevada). There are many other known geothermal resource areas in the United States that are under consideration. However, none of these other areas has been the subject of extensive air-quality studies such as those conducted in The Geysers and Imperial Valley.

FIGURE C-2 1976 TO 1978 TRENDS IN PERCENTAGE OF HOURLY H_2S CONCENTRATIONS AT OR ABOVE 20, 30, AND 40 ppb