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Proposal

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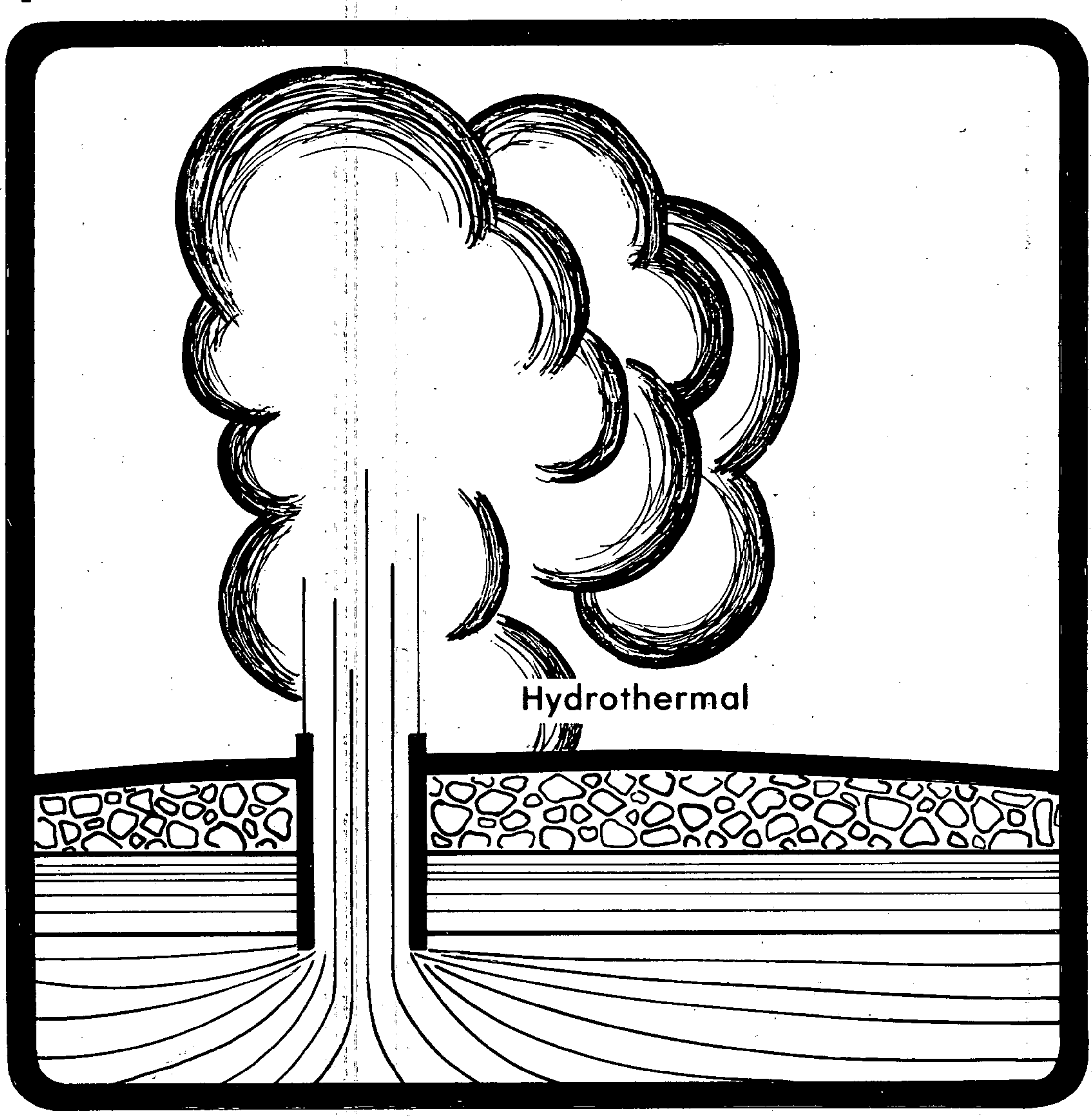
A Study of the Potential Health and Environmental Impacts from the Development of Liquid-Dominated Geothermal Resources



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Los Alamos National Laboratory
Los Alamos, New Mexico, 87545

DISCLAIMER

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Edited by
Joel M. Williams

Contributors

L. R. Anspaugh
Lawrence Livermore National Laboratory

S. Barr
Los Alamos National Laboratory

F. P. Hudson
DOE/OHER, Washington, DC

D. E. Robertson
Battelle Pacific Northwest Laboratory

J. H. Shinn
Lawrence Livermore National Laboratory

G. C. White
Los Alamos National Laboratory

J. M. Williams
Los Alamos National Laboratory

Prepared for the
US Department of Energy
Director of Energy Research
Office of Health and Environmental Research
Washington, DC

Los Alamos

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

CONTENTS

A STUDY OF THE POTENTIAL HEALTH AND ENVIRONMENTAL IMPACTS FROM THE DEVELOPMENT OF LIQUID-DOMINATED GEOTHERMAL RESOURCES

Edited by

Joel M. Williams

Contributors

L. R. Anspaugh, S. Barr, F. P. Hudson, D. E. Robertson, J. H. Shinn, G. C. White, and J. M. Williams

ABSTRACT

This document describes seven programs to provide scientific input, understanding, and forecasting capability for hydrothermal energy areas needing resolution. The three major areas addressed are (1) the impacts on living components of the aqueous and terrestrial ecosystems, (2) the impacts on the quality of the abiotic environment itself, and (3) the techniques needed to measure releases from hydrothermal activities.

INTRODUCTION

Geothermal steam and hot-water resources could provide as much as four percent of the nation's heat and electricity requirements by the year 2000, using currently available technology. The technological problems in developing a substantial portion of such geothermal resources are minor, but real or perceived environmental issues could deter development. Basic and generic environmental research applicable to a wide range of geothermal resources and locations is needed to support development of these energy sources that promise relatively quick and low-cost payoffs. The studies described herein provide such an approach to the assessment of environmental and health-related issues that might delay development of liquid and steam-dominated geothermal resources. These studies are aimed at alleviating public concern over vaguely defined environmental issues and at providing DOE and the industry with an understanding of the characteristics and consequences of accidental or continuous pollutant releases and with the data, "tools," and methodologies to deal with them effectively.

A number of diverse environmental issues need to be addressed to smooth the way for geothermal energy development. Some are political, regulatory, or socioeconomic in nature. Others, such as aquifer contamination and drawdown, aquatic and terrestrial degradation or modification, brine spills, cooling tower releases, and hydrogen sulfide emissions, need scientific input to be answered properly. The scope of geothermal environmental concerns and the capabilities needed to address them have been determined through a major program of experimental and analytical environmental studies in the Imperial Valley Known-Geothermal-Resource Area (KGRA) of California and through a series of broadly attended workshops in the country's other major KGRAs. Minor field-experimental programs at The Geysers in California, Raft River in Idaho, and the hot dry rock site in the Jemez Mountains of northern New Mexico have provided additional important data. Some relevant publications printed since 1976 are given in Appendix A.

The workshops and measurement programs conducted thus far have generally shown that all geothermal sites have a common set of problems. The principal concerns are the contamination of potable water supplies by geothermal effluents; the availability of supplementary water required for operation of electrical-production plants; the presence of malodorous gas in plant gaseous emissions; the subsidence of land; and the potential ecological effects of effluents. The relative importance of these concerns at any given site may vary considerably, however. For example, land subsidence is the principal concern in the Imperial Valley, and the disagreeable odor of hydrogen sulfide is the principal concern in the Geysers area, whereas water-related issues are the major problem in New Mexico. Because sites to be developed in the future may have any of these as an important concern, the capability of addressing each concern in any region is needed.

To effectively evaluate and resolve potential environmental problem areas, one needs to know the overall magnitudes of the problems that will result from developing any geothermal energy source and the variability at different locations. The variation in importance of concerns at different sites is a reflection of the variability in the geothermal resources and their geologic location. The Imperial Valley development has a water-dominated source in an agricultural area, whereas the Geyser area has a steam-dominated source (and a water-dominated one to be developed) in mountainous terrain, as does the water-dominated development in northern New Mexico. The mountainous terrains are more typical of geothermal areas and tend to channel pollutants whether they are airborne or waterborne. The uplifted land also creates significant perturbations, especially in airflow, and often form the headwaters of areal water supplies.

If treated as a common entity, the environmental issues associated with geothermal-energy development can be addressed more systematically, and each new site becomes a tractable variation about a central pattern, rather than a new case having only limited connection with the previous one. A well-defined protocol is needed that will define pertinent issues, develop and standardize the methodologies for evaluating and addressing those issues, and provide sound, credible assessments of each situation. If such a protocol is based on good science, it will provide a solid basis for assessing health and environmental risks, granting permits, evaluating the suitability of sites, and making decisions on mitigation requirements or operational changes.

NEEDS FOR GENERIC ASSESSMENTS

Specific delineation of the true character and range of potential concerns and their remedy at all sites are needed. This requires that the interactions of the energy process with the surrounding environment and the responses of those interactions to mitigating efforts be coupled and set to a standard protocol. Several major studies, oriented around broadly attended workshops, have specified the environmental questions related to the use of geothermal resources. The extensive, preliminary assessment of the environmental issues in the Geysers-Calistoga area,[1] published in eight volumes, pinpointed nineteen issues as needing more research and assessment efforts in the Geysers-Calistoga region, a location that accounted for one-third of the geothermal electrical production in the world in 1978. The Imperial Valley Environmental Project (IVEP), which was completed in July 1980 with the publication of a two-volume assessment[2] of the consequences of the development of a full-scale geothermal industry in the Imperial Valley, defined the hierachy of problems there. Numerous other projects are being funded or have recently been funded (see Appendix B). Considering the scientifically based, but unanswered, questions that have been raised (especially with regard to the development in the Jemez Mountains of New Mexico), even more information is needed in many areas.

A two-pronged approach is proposed considering the immediate (site specific) and long-term (generic) deficiencies. Generic assessment methodology should concentrate on specifying what answers are needed to make the decisions in the final stages for an acceptable environmental development of geothermal energy. Scientific efforts should address the most obvious deficiencies in environmental assessment and provide a broader, more comprehensive base from which to derive needed answers. A good start has been made in the extensive data-bank of environmental measurements made in the Imperial Valley of California. These data have been formatted to allow computer access by Federal, state, local, industrial, and public-interest groups. Further research needs will be described herein.

A GENERIC-MEAN DEVELOPMENT SITE

The prototype of any model or assessment should include the most probable conditions and soundest predicting capabilities. No real site may ever be found to be like the prototype but many should come close. A generic mean establishes the norm and provides the standard to which specific cases can be compared and evaluated. The following paragraphs begin a qualitative definition of a generic-mean, geothermal energy development site.

A typical liquid or steam-dominated geothermal area is likely to have a complex, mountainous terrain, although the flat, agricultural terrain of the Imperial Valley is an obvious exception. Wind patterns will also be complex with concentrating valleys, dispersing meadows, and occasional stagnant pockets. Precipitation will occur as rain or snow in spotty, but moderate, amounts. Streams are likely to be small, but recreationally and agriculturally important. Animal life is also likely to be well established with larger species being sought as game. Human inhabitants are not likely to be numerous, but will be sensitive to environmental matters. Vegetation is likely to be well established and neither scant nor abundant. Generally a development will disturb 10-20% of the land and vegetation in the well field to provide for the well-pads, laydown and staging areas, pipelines, flashing and power stations, office buildings, transmission lines, etc.

The predominant type of geothermal development over the next decade or so will use hot water reservoirs, although steam is currently the only commercial resource in the US, and hot dry rocks provide the largest ultimate resource. The energy fluid will be drawn up by a number of wells from a subterranean system that will probably be highly contorted as the result of the mountain forming processes. It will be a brine with elevated levels of a few chemical elements and hydrogen sulfide. The energy fluid will be transported overland through pipes to the powerplant. Spent fluid will be transported back to the well field for reinjection. The amount of fluid moved will be inversely related to the temperature of the energy fluid and to the amount lost during energy extraction. Much more fluid will be transported and handled with hydrothermal resources than for comparable energy from steam-dominated resources, but the spent fluid segment should be similar in kind, if not magnitude. A net withdrawal of fluid from the well field will most likely occur.

The predominant use of geothermal energy in the foreseeable future will be for electrical generation, although direct, nonelectrical use has considerable potential. Extracting steam by pressure-release "flashing" and using it to run turbines is the current technology. (For lower temperature fluid resources, a binary, heat-exchange system may become the norm as the flashed-steam method is less efficient for lower temperature fluid.[3]) Spent steam is condensed and cooled in a cooling tower before being returned to the well field to be reinjected. Obnoxious hydrogen sulfide is removed chemically to prevent its escape.

The generic-mean site sketched above should be a reasonable representation of the situation at any specific site. The problem is in quantifying the mean and evaluating the sensitivities of responses when moving away from the mean. Some portions of a geothermal site can probably be quantified now, but some, e.g., resource drawdown, appear to be far from this stage. The need is to quantify those parameters that are critical, and to document the others as not critical.

AREAS WITH SCIENTIFIC DEFICIENCIES

During the spring of 1980, Los Alamos National Laboratory conducted two meetings to evaluate those issues that are the most critically in need of additional research to smooth the way for water-dominated, geothermal energy development. The emphasis at the meetings was on issues involving environmental impacts outside the production area. This recognized that safe, nonpolluting conduct of business on location is the problem of the producers and generally regulated for all industries. Participants were representatives from industrial geothermal energy suppliers and electrical producers, from the DOE geothermal demonstration office, and from the national laboratories working on geothermal environmental projects.

The dominant environmental concerns connected with hydrothermal development include water quality, terrestrial impacts, air transport and dispersion of contaminants, health effects, impact on wildlife, noise, erosion and siltation, solid wastes, and seismicity. Solid waste, erosion, and sedimentation are common industrial problems that are widely addressed. Noise is a potentially serious occupational problem that will be handled by the developers. Seismological studies are currently being conducted by Lawrence Berkeley Laboratory. The other concerns listed are the subject of this proposal. They fall into the three categories below.

I. To address the impacts of hydrothermal activities on the living components of the aqueous and terrestrial ecosystems, efforts are needed to:

- Assess the potential impacts of geothermal brine spills on terrestrial and aquatic ecosystems;
- Assess the effects of deposition and resuspension of cooling tower drift components on terrestrial and aqueous ecosystems;
- Determine the chronic impacts of hydrothermal plant emissions on human health; and
- Determine influences on wildlife habitat and health.

II. To address the impacts of hydrothermal activities on the quality of the abiotic environment itself, this and related programs must:

- Develop a capability to measure and predict how H_2S and other airborne contaminants disperse in complex terrains, and
- Evaluate the potential impacts of hydrothermal-energy fluid extraction on regional water resources.

III. To determine what specific hydrothermal activities release into the environment, techniques must be developed to

- Characterize the pollution sources at the production site.

New techniques and computational models will also be needed to evaluate and predict the impacts of the hydrothermal activities on the ecosystems. Particularly noteworthy is the need to understand and predict brine transport in the terrestrial and aquatic components.

RESEARCH PROGRAMS TO ADDRESS SCIENTIFICALLY DEFICIENT AREAS

This section contains a series of seven programs that would be carried out by various national laboratories to provide scientific input, understanding, and forecasting capability for those topics described in the previous section as needing resolution. Although suitable specific sites will be used for any field measurements or samples needed, the programs are aimed at providing generic results. Principally, the Geysers and Imperial Valley of California and the Jemez Mountains of New Mexico will be used in an effort to provide the best resolution of each problem. Other US or world sites will be used as appropriate. Each program will be conducted by the organization with the best background for addressing that program. The programs are presented collectively under common areas.

I. Impacts of Hydrothermal Energy Development and Its Releases on Aqueous and Terrestrial Ecosystems.

A. Acute Effects of Accidental Brine Releases (Los Alamos)

The program described here addresses the problems that would result from infrequent but substantial spills of brines from pipelines or holding ponds. Potential sources of brine spills include discharges of raw brine prior to its entering the power plant, and of spent brine prior to its reinjection. Acute conditions are likely to be thermal and salinity shock and elemental toxicity. Cumulative large spills could present chronic problems even if acute problems are not found. Los Alamos National Laboratory will be responsible for determination of (1) brine spill effects on water, soils, and plant life; (2) spill size and time toleration limits of ecosystems; and (3) measures needed to reclaim or clean up contaminated areas.

1. Order-of-Magnitude Studies of Acutely Toxic Brine Spills

The available data on accidental spill frequencies will be normalized to project likely occurrences and magnitudes for spills at hydrothermal sites. Published tables of total dissolved solids and element analysis will be obtained from available hydrothermal sites for qualitative identification of potential chemical interaction, speciation, and potential toxicity. Estimates will be made of the probable size and area of potential spills, the retention time of pollutants, and the magnitude of acute and chronic effects.

2. Brine-Soil Interactions

Rates of runoff and percolation will be studied to determine the extent of infiltration and the time to reach ground water. Physicochemical studies will be made under controlled conditions of adsorption, coprecipitation, speciation, biological availability, partitioning behavior, chemical buffering capacity, and moisture retention. Effects on soil composition, depletion of available nutrients, and mobilization of trace metals will be studied. Changes in brine composition, pH, redox potential, and trace metal speciation will be investigated. Bioassays and indicators of toxicity will be used to screen brine effluents for potential toxicity to plants, microbes, and other terrestrial systems.

3. Brine-Water Interactions

Direct discharges of brine into surface water will be investigated, beginning with rates of mixing and diffusion of solutes. Physical interactions of the mixture by sorption on sediments, partitioning between sediments, and buffering will be studied. Aqueous chemistry studies will specify pH plus speciation and mobilization of trace metals. Bioassays and indicators of toxicity to aquatic organisms will be used to screen for potential adverse effects. Transport to groundwater will be assessed.

B. Chronic or Low-Level Ecological Effects from Brine-Related Effluents and Deposited-Emissions (LLNL)

This program addresses potential chronic problems that may result from long-term deposition of low pollutant levels into the surrounding landscape and their eventual mobilization into the soil or aquatic systems. The sources of long-term, low-level releases are mineralized droplets, solid aerosols from transformed cooling tower emissions, and possibly, vapor emissions originating from the brine, brine additives, or sulfur abatement systems. Previous research and assessments have indicated that the major, acute environmental impact of geothermal resource utilization is from the effluent escaping through cooling tower drift. There are two components of the cooling tower effluent: a close-in deposition that has been known to have phytotoxic effects, and a long-range transport component that has not been adequately described and may cause environmental effects at the ecosystem level.

Each geothermal field will have its own specific suite of elements and compounds that will enter the cooling water stream. Boron, sulphates, chlorides, fluorides, and, in extreme conditions, iron, are known or suspected phytotoxic agents that have been found in cooling tower water at the Geysers in California. Atmospheric cooling tower effluent will interact first with the foliage of the dominant vegetation when it is deposited as an aqueous aerosol or dry particulates. Secondly, the cooling tower effluent will be integrated by the landscape and will appear in surface runoff from the encircling watershed. The highest deposition occurs within a few hundred meters of the cooling tower. Early assumptions about cooling tower drift being entirely localized, however, may be optimistic.[4] Lawrence Livermore National Laboratory will determine (1) whether "cooling tower drifts" have effects over larger geographical range than currently believed, and (2) whether there are chronic impacts from long-term exposures to low-level pollutants.

1. <u>Order-of-Magnitude Studies of Chronically Toxic Depositions</u>

Previous and current studies at the Geysers area will be used to develop a conceptual model of the transport of hydrothermal pollutants over large geographic areas. Qualitative identification of drift components will be made and possible transport mechanisms identified. An evaluation of this model will include the establishment of regional concentrations present before a power plant begins operation and their changes during operations. Measurements of baseline concentrations of particulate, gaseous, and organic constituents in the mesoscale atmosphere will be made as required near an undeveloped site during representative periods in the summer and in conjunction with air transport modeling studies or monitoring efforts. A mobile laboratory that has been used at other geothermal power plants and KGRAs will be used as a field base of operations. Gas analyzers and basic meterological equipment with computer data logging and conversion will be used to make the baseline measurements. High-volume air samplers will be deployed to obtain airborne particulates that will be analyzed by x-ray fluorescence, neutron activation, or inductively coupled, argon-plasma emission spectroscopy. Passive integrating samplers will be placed in several locations. These samplers were used with success at the Geysers.

The potential distribution of effluents around power plants will be estimated and the mechanisms and rates for the transfer of chemical species to soils and watersheds will be determined. Quantitative baseline concentrations of anticipated cooling tower drift constituents in the vegetation of the predicted depositional area will be established. Elements and compounds such as boron, fluorine, sulphate, iron, arsenic, lead, and chlorine will be analyzed in a selected series of the dominant shrubs, trees, and grasses of a site. The likelihood for phytotoxic effects from chronic exposure will be addressed.

2. Drift Deposition-Soil Interactions

Deposition rates to soils and vegetation will be determined at the Geysers and Imperial Valley. The infilration rates of deposited minerals during precipitation and other weathering sequences will be measured. Low-level physiocochemical effects, such as changes in speciation before and after deposition, soil accumulation, bio-accumulation, and leachability, will be studied. The potential chronic effects on microbes and other terrestrial systems will be determined.

3. Drift Deposition-Water Interactions

Deposition of drift contaminants directly into water and the dissolution of soil-deposited drift components in rain-simulated runoff will be determined. Deposition to snow will provide an attractive monitoring technique at some locations. Low-level physiochemical effects, such as the dilution of drift-contaminated runoff waters in streams, alluvial transport, and sediment interactions will be studied. The potential chronic effect on aquatic organisms will be assessed.

C. Chronic Impacts of Hydrothermal Plant Emissions on Human Health (LLNL)

Technology assessments are mainly structured to provide an analysis of residual effluents and projected impacts upon air and water quality. These assessments are incompleted because they do not conclude with projected quantitative impacts upon human health and ecological systems. The primary reason for the lack of such conclusions is the absence of response-vs-dose functions for many of the pollutants.

Emission of hydrogen sulfide gas has been the most significant health concern related to the development of geothermal resources. Abatement systems are now being perfected and installed. They are not 100% efficient, however, and remaining emissions, thought low, still leave questions, especially those related to chronic human exposure. Standards for public exposure are usually related to the odor perception threshold rather than to concentrations demonstrated to be injurious to health. The odor perception threshold for hydrogen sulfide is very low at about 0.0005 ppmv. At intermediate concentrations of about 0.1 ppmv, numerous health problems have been alleged to occur but have not been proven. The current USNIOSH recommended standard for occupational exposure (10 ppmv for a 40-h week) is over a thousand times the odor level with the requirement of evacuation if the concentration exceeds 50 ppmv, the threshold for serious eye injury. The lethal concentration is 1000 ppmv (200,000 times the odor threshhold).

Hydrogen sulfide causes local irritation of moist membranes and body function (systemic) changes when absorbed through the lung or gastrointestinal tract. The systemic response is attributed to reversible inhibition of cellular cytochrome oxidase by molecular hydrogen sulfide. Humans and animals have a detoxification mechanism that oxidizes hydrogen sulfide to harmless (at this level) sulfate. Guinea pigs, for example, are capable of detoxifying 85% of the single lethal dose of sulfide each hour. Since the inhibition is reversible and the detoxifying mechanism is efficient, hydrogen sulfide is considered to be a noncumulative poison. No clear evidence demonstrates whether hydrogen sulfide does or does not cause deleterious effects at very low concentrations. Some equivocal evidence suggests that long-term chronic exposure to hydrogen sulfide may produce neurasthenia and other diseases. In any case, evidence demonstrates that the effects, if any, must be small. Unfortunately, such minimal chronic effects have not been studied using a relatively large human population base.

The two-pronged program described below would be conducted by Lawrence Livermore National Laboratory.

1. <u>Health Response to Hydrogen Sulfide</u>

An epidemiological study of the population at Rotorua, New Zealand, would be conducted. Rotorua presents an excellent opportunity to study a relatively large number of people exposed to concentrations that are very high relative to most public exposure standards, but are still an order of magnitude below occupational exposure standards. This is the principal urban area in a natural geothermal zone. Half of the 40 000 people live in the geothermally "hot" areas of the city and are exposed almost daily to hydrogen sulfide concentrations around 0.4 to 0.7 ppmv for at least 8 hours. This appears to present a unique opportunity to study long-term effects on a reasonably sized population.

The study would determine the exposure levels, perform mortality and morbidity studies, and quantify the relationship between human health and exposure to hydrogen sulfide. The exposure levels in Rotorua would be documented by accumulating available data and by making additional measurements. The mortality study would compare rates of mortality in Rotorua and suitable control areas. The mortality records are reasonably good because the country is geographically small and health care is quite standardized. All death certificate data are available from the National Health Statistics Center. A study of carcinogenesis would be accomplished by using the very good New Zealand Cancer Registry, which covers nearly all the inhabitants. Data collected since 1980 by the fetal defects registry is also very good. Though hospital admissions data may not be adequate for looking at chronic respiratory diseases, reasonably good studies may be possible to examining the records of individual practitioners. A comprehensive review would be generated to reflect the interrelationships of these documented data and exposure to hydrogen sulfide.

2. Assessment of Health Responses to Emissions

A series of annual Health and Environmental Effects Documents for geothermal energy development would be produced. Previously completed geothermal and environmental studies and assessment would provide necessary data to define residual effluents and predicted impacts on air and water quality. The primary goal of the assessment is to quantify the health and environmental effects of using geothermal energy.

Models of ecological and human health response to most pollutants are generally unavailable, and their development and application will be important goals of this effort. A major activity would be to derive dose-response functions for the pollutants: hydrogen sulfide, mercury, arsenic, radon, and benzene. The effects of cooling tower drift on crops and humans via food-chain transfer would be described because geothermal condensates are frequently used as cooling water and may contain high levels of toxic elements, such as boron or one of the heavy metals. This effort would depend upon the use of response data for exposure of both ecological systems and man to the pollutants. Data from many federal programs, particularly those funded by the DOE/ OHER, FDA, EPA, and NIH, would be used. The expertise at LLNL and Los Alamos is available for use to assess the carcinogenicity, mutagenicity, and teratogenicity of pollutants. LLNL and Los Alamos expertise is also available to help develop models of transport, fate of pollutants, and ecological response. The data from California on occupational illness and injury in the geothermal industry would be examined in more detail to define rates of occurrence.

D. Changes in Wildlife Habitat Use Due to Hydrothermal Development (Los Alamos)

Development of geothermal resources will result in the modification of habitat through removal of vegetative cover at site and corridor facilities and through increased human presence and activities. In addition, accidents resulting from geothermal equipment failure may provide sources of toxic chemicals to animals and their consumers through forage and drinking water. Full-scale field development will result in increased noise and human activity near geothermal activities. Elk, for example, are known to avoid areas of human disturbance and activity and may continue to be influenced by these disturbances for several years. Although the habitat modifications that occur during site and corridor construction and operation activities can be measured, the effect of such modifications on an animal species is very difficult to quantify without understanding the relationships between the animal and its habitat.

Each species of wildlife forms a link in the ecosystem. Some are carnivorous, others herbivorous or omnivorous. Significant changes in any link will affect the whole system above that link. Fortunately many species draw their existence from a number of links and can adapt to imposed changes. The problem in assessing the effect of a development becomes one of determining if a species is affected, how much it is affected, and whether such an effect is vital to the wildlife chain or a minor perturbation, either favorable or unfavorable.

The first stages of an environmental impact study generally define the numbers, types, etc. of wildlife in the development area as a baseline. Monitoring is typically used to keep trace of any changes. Small-animal traps provide a convenient way of inspecting such animals for disease, weight, etc. and estimating population density. Small-animal studies are common and may be inexpensive. Such studies are limited, however, by the restricted movement of the small animal and typically measure the influence of only a small portion of the physical changes made by a development as they influence the animal's small home range. Large-animal studies provide a means of measuring influences from a large portion of the physical changes as they cover large areas of land.

The general goals of the study outlined below are to (1) develop quantitative methods for assessing the impact of energy resource developments on the wildlife in geothermal areas and (2) determine the response of wildlife to various activities so that constructive action, if necessary, can be taken. Specific objectives are to (1) document use of habitat by wildlife in relation to geothermal site and corridor developments and (2) provide a basis for assessing the changes in habitat use as further geothermal developments occur. The efforts described in the study would be performed by Los Alamos National Laboratory to determine habitat utilization by elk or other Cervid species in an area that is in initial stages of hydrothermal energy development. Some specific questions to be answered are

1) What habitats (food, cover) are used by animals on winter and summer ranges and during migration?
2) What environmental factors stimulate animal migration?
3) Do individual animals show fidelity to winter and summer ranges and to migration pathways?
4) How are animal survival rates affected by a hydrothermal development?

Los Alamos is currently conducting biotelemetry studies of elk in the National Environmental Research Park near Los Alamos, NM, and of mule deer in the oil shale development area (Piceance Creek Basin) of Colorado and is uniquely suited for the conduct of this study. Generally, the proposed study will provide documentation of the change in use patterns and should provide a course for mitigating these effects in future geothermal development.

Initial trapping operations in a hydrothermal development area would be conducted during the period when the animals are residing in the development vicinity. A minimum of 40 individuals would be fitted with radio-collars. During trapping periods thereafter, additional animals would be radio-collared to maintain a representative sample of animals and to replace those subjects lost by radio failure or mortality.

Both aircraft and field reconaissance methods would be used to follow the radiocollared animal. The frequency at which the animals would be located would depend on the relative movements of the individual animals. Radio-collared animals using areas near the geothermal development would be monitored intensively during several 24-hour periods to identify responses to noise and human presence. In addition, experimental pertubations would be imposed on radio-collared animals to determine their response behavior.

Biotelemetry data collected on radio-collared animals would be summarized in a computer-generated 16-mm color movie to permit the time dimension to be included. Geothermal tract features, including corridors (i.e., roads, powerlines, etc.), would also be displayed on the base map to illustrate their hinderance or aid to migration. Animal reaction to transmission-line and site construction would be evaluated. Hypotheses about differences in the movements of the animals by age and sex classes would also be tested to determine influence on herd stability and reproduction. In addition, universities would be involved in studies to determine responses of biological factors, such as disease, diet, mating, etc.

II. Impacts of Hydrothermal Energy Development on Air and Water Resources

A. Dispersion of Airborne Contaminants in Complex Terrain (Los Alamos)

A sound understanding of the transport of trace contaminants in the air is needed for a systematic development of a geothermal energy industry at any location if environmental protection regulations for the atmosphere are to be met. The transport, dilution, and ultimate fate of airborne materials depend strongly on topography, wind, temperature, moisture, turbulence, and removal processes. A basic understanding of these parameters is among the most critical early needs in assessing expected environmental effects and in formulating an environmental monitoring program. Background concentrations of critical airborne contaminants, such as H_2S, and some trace elements are also needed. Having carefully documented the existing natural background and the increments added by each newly developed facility, a rational plan for siting a number of power plants can be formulated.

Computational models are not yet capable of defining atmospheric transport of pollutants through the complex terrain where hydrothermal sites are likely to be developed. Several research institutions are working together through the DOE-Sponsored ASCOT program (Atmospheric Studies in Complex Terrain) to remove this constraint. Currently, the behavior of nighttime downflow of cold air through valleys is beginning to be understood. Some interpolative capabilities are arising as empirical definitions parallel fundamental studies.

The selection of sites as natural laboratories to study air transport of materials depends strongly on need and desirability. The need is often related to the urgency for answers and the size of the commercial venture. Desirability is related to the physical assets of the site that make it favorable for testing and formulating models. The conduct of the major ASCOT effort to study air flow at The Geysers in late 1980 was strongly influenced by the presence of the large geothermal industry there and the criticality of the H_2S problem. From a fundamental point of view, however, the valleys there are not well defined. The data gathered is still being analyzed, but the extreme complexity of the terrain should present a case on which to evaluate refined models in the future as well as providing some directions now. The next large ASCOT effort will be in the oil shale region of Colorado. This again is a high-need location, but with very different terrain (very desirable for variety) than found at The Geysers. Moving to the Jemez Mountains of New Mexico for the third set of field studies would meet both desirability and need criteria.

The Jemez Mountains of New Mexico offer a variety of strong points as an air-transport modeling site. The hydrothermal development site has a good topography with a fairly well defined canyon having high walls. The air is relatively clean, with ample sunshine. This will permit good studies of photochemical reactions that produce "photochemical smogs." The proximity fo the Los Alamos National Laboratory will provide an excellent physical plant and expertise for the base camp. In addition, baseline meteorological data have been assembled over a 5-year period at Los Alamos' Hot Dry Rock (HDR) energy site about 10 km from the proposed hydrothermal site, and data are continuing to accrue. The HDR site is exposed to the prevailing winds and represents an excellent site for documenting the general meteorological conditions that will occur at the hydrothermal location. Considering these points, preliminary work to prepare for future ASCOT studies using the Jemez area seems appropriate.

Los Alamos National Laboratory would conduct studies in cooperation with the ASCOT program to determine the dominant characteristics of the wind, temperature, moisture, and turbulence fields caused by the topographic setting at the Jemez hydrothermal location. The results of this early characterization will guide later design of meteorological and air quality modeling and monitoring programs as well as the interpretation of broader scale environmental surveillance data. The monitoring programs that are developed would be directed toward documenting the extent of microclimate modification and estimating chronic and acute air-quality degradation and pollutant deposition to the ground.

1. Baseline Air-Pollutant Transport Studies in the Jemez Mountain Region

The baseline evaluation would include identification of general and seasonal climatology and estimates of important pollutant transport scenarios and preliminary meteorological and baseline air-quality scenarios. Related upper-air climatology would be derived from a nearby upper-air station (for example, Albuquerque) to highlight major wind statistics, such as the free-stream airflow conditions, that are modified by the local topography. Thermal stability, mixing depth, and elevated inversions would be derived from conventional National Weather Service records. A simple network of surface meteorological observations would be based on these preliminary estimates. This would likely include canyon to ridge differences in winds, turbulence, and temperatures derived from two to four measurement sites along critical pollution paths. Sampling would cover several months in all seasons. Supplementary upper-air soundings of wind and temperature, plus a few tracer tests, would help identify the important air quality scenarios. An initial survey of critical pollutants (H_2S and B) would be done with simple techniques at enough sites to evaluate pollutant dispersion. One or two standard sites with more detailed airquality monitors would be set up for continuity. Data being collected by the hydrothermal site developers would be included to minimize duplication.

2. Modeling Air Pollution

After a careful interpretation of the preliminary field observations and using the available model estimates of transport and dilution of emissions, and intensive field measurements program would be initiated by ASCOT. This task would concentrate on the structure and mechanics of important wind, temperature, and turbulence fields and their effect on the fate of emisisons. Tracer release and sampling experiments would be included in 1- to 2-week field efforts to be conducted in each of the major seasons. The large quantities of data generated would be reduced, interpreted, and compared with the generic model estimates. The generic model would be modified, and a network sufficient to monitor the parameters critical to air quality would be designed and tested. Once a working network has been documented, operation would pass to the industry.

B. Impact on the Water Supply and Quality in the Production Region (Los Alamos)

Water resources in geothermal production areas, like most other regions, consist of an active surface watershed with shallow and deep aquifers. Surface water flow is confined primarily to watershed runoff from rain and snow and from shallow aquifers and springs. Data on surface water supply and quality is generally acquired in the early stages of a site evaluation, if not previously documented. Flows in the streams are generally small but may be persistent and seasonally variable. Water quality in these waterways should be good, being a natural fresh water source, but some mineralization may result from mineral spring inputs. Surface water is usually supporting aquatic life and is often used downstream for agricultural proposes. Loss of good water is becoming critical nationwide; a loss in the water-deficient southwest could have serious consequences.

Deep aquifers, mainly in the production zone, will be impacted by hydrothermal power development. The question is whether the impact will be severe enough to be a problem. Besides drawdown and pressure drop in the reservoir, reinjection of cooler, more concentrated, salt-brine fluids is likely to create significant temperature gradients and increased dissolved solids in the production aquifer. Although seismic effects might be undetectable, cross-aquifer contamination around the many wells required to support a hydrothermal power plant is a possibility. If this does occur, surface water quality may be affected by the project.

The complexity in assessing water supply and quality effects is illustrated by the disparity in evaluations related to the proposed hydrothermal demonstration plant in the Jemez Mountains of New Mexico. One evaluation predicts that little (less than 1%) loss in surface water flow will result during a 30-year plant (50-MW_e) operation. Another predicts that a catastrophic (75%) loss of the surface water related to the production zone will occur.

Water resources in complex mountainous terrain are difficult to evaluate because of the faulting and twisting of the earth to form these contorted mountain structures. Unlike many "flatland" areas in the United States where the water system might flow parallel to the surface and through small-pored aquifers, the water system in such mountains could be expected to have a significant vertical component along fault lines or vertically oriented earth layers capable of transporting water. Drawdown of water in the "flatland" areas might be expected to radiate uniformly from a well site. Drawdown from a fault-dominated system should be highly specific along certain radii only. The prime question is how much influence geothermal wells in this type of terrain will have on water supplies, particularly thermal springs, that might be directly (or indirectly) connected to the pumped water system.

Degradation of water quality by hydrothermal development is also difficult to evaluate. (Degradation originating from surface spills and cooling tower emissions are covered above.) Boron concentrations in the supply steam have been observed by LLNL to have risen over the years at the Geysers geothermal area. Elevation of this element by reinjection is one explanation. In a complex terrain, production and reinjection wells might be connected together with the regional water supplies, independently or together. Thus, areal water supplies could degrade, diminish, do both, or do neither as the result of hydrothermal activity. Because of this, water quality is also intimately tied to the evaluation of how an energy technology will influence water supply.

Uncertainty in predicting the effects on areal water resources is at the heart of the problem. This issue has been a persistent issue in the series of environmental workshops to evaluate environmental restraints on geothermal power developments. The uncertainty is related to an insufficient understanding to formulate the problem definitively, and lack of sufficient information to resolve it. The deficiencies make it difficult to model and predict responses in a system that can best be described as "a tough nut to crack." Since many other mountain areas are also prime spots for hydrothermal energy developments, questions about their influence on water supplies will arise again and again. The time seems right for tackling it.

Los Alamos National Laboratory proposes to conduct a program to evaluate current knowledge, to identify gaps in the present methodology, to determine the critical parameters controlling the hydrology in mountainous terrain, to identify needed data, and to evaluate what is required in a model for predicting water resource behavior. This program would establish the state of affairs and create a program capable of resolving the deficiencies in understanding water-resource behavior.

III. Pollution Source Characterization (PNL)

The high-temperature magmatic processes that create the hydrothermal provinces result in a accumulation of gases and liquids that can be released when these reservoirs are tapped. Gaseous contaminants include H_2S, mercury, radon, ammonia, boron, and carbon dioxide. Many liquids contain high concentrations of toxic trace elements, including Hg, As, B, Sb, Se, Te, Cu, Zn, Pb, Ag, Mn, Ni, and Cr. At the present time the range in concentrations of toxic materials in geothermal fluids from a few locations is known. From this experience it is evident that the range is considerable and chemical speciation poorly known.

Detailed measurements of gaseous cooling tower emissions at Unit 15 in the Geysers have been made in cooperation with Pacific Gas and Electric staff. Two stacks on the Unit 15 cooling tower were analyzed for air flow distribution, temperature, H_2S, Hg, and NH_3 at 24 different locations within each stack. These measurements indicate the extremely variable nature of the parameters within each stack and the need for careful studies to adequately determine emission rates. Mass balances of geothermal pollutants through these plants need to be studied, and emissions routes to the environment need to be evaluated. These determinations should permit more complete observations made at existing geothermal power plants, such as those at the Geysers and Cerro Prieto, Mexico, to be extrapolated to other areas where geothermal power will be developed.

The accumulation of toxic heavy metals and trace elements in soils and vegetation surrounding geothermal power plants provides an environment for alterations in chemical species to occur. For example, inorganic mercury accumulations may be transformed by soil bacteria to the more toxic methylmercury species. Conversely, highly toxic, inorganic As(III) could be transformed during vegetative or animal uptake into the innocuous, methylated, organic forms. No information exists that describes the chemical forms of Hg, As, B and other toxic contaminants in soils or vegetation at geothermal sites.

Battelle's Pacific Northwest Laboratory (PNL) has been a prime developer of source characterization techniques at the Geysers, CA. In addition, they have participated in the environmental programs at other development sites aided by DOE, including Raft River, Idaho; Tigre Lagoon, Delcambe, Louisiana; and the Hawaii Geothermal Project at Puna, Hawaii. The following program points out additional characterization studies that are needed and would be conducted by PNL.

New and improved sampling methods and analytical technology for the analyses of geothermal gases and heavy metals in gaseous and water soluble forms would be developed. The analyses of these fluids are complicated by a variety of chemical constituents, which create precipitation reactions, interferring matrices, and other problems that can affect the validity of analyses. The effects of these various parameters on the sampling, storage, and analysis of geothermal fluids would be examined. Efforts in determining the physiocochemical speciation of trace metals in geothermal fluids would be expanded. New techniques are needed to determine the chemical forms of the volatile trace metals Se, Sb, and Te in gaseous forms, and methods need to be developed for determining the chemical forms of trace metals dissolved in geothermal waters. As new geothermal wells become available for study, they would be included in the field sampling programs. Studies of cooling tower emissions would be expanded and a greater emphasis placed on measuring the drift emissions.

More explicitly, steam, noncondensable gases, steam condensate, and separated brine or hot water would be sampled and tested for heavy metals, H_2S, radon, ammonia, boron, and other chemical constituents. Field measurements conducted at the test sites would include mercury speciation in geothermal fluids and analysis of H_2S, S^-, F^-, HN_4^+, pH, and Eh. Condensate samples, hot-water or brine samples, gas samples, and scrubber solutions of noncondensable gases would be collected for laboratory analyses of a large group of trace metals, including As, Se, Sb, Te, Cd, Zn, Pb, B, Ag, Cu, and Cr. Chemical speciation measurements for As, Hg, and possibly Se, Sb, and Te would be made. Gases that will be measured include CO_2, CH_4, N_2, Ar, Rn, and others. A major emphasis would be made in evaluating the benzene emissions in geothermal effluents that have been tentatively identified at a number of locations. Where completed generating units are on line, mass balances of steam pollutants through the power plants would be conducted and important release routes to the environment would be evaluated. An important part of the emissions study is the proper characterization of complex pattern of emissions from geothermal plant cooling towers. The efficiency of various abatement processes and their concurrent effects on other pollutants would be examined.

A concerted research effort would be directed towards elucidating the chemical forms of these contaminants and the environmental transformations that may occur, which make them either more or less toxic and biologically available. Efforts would be concentrated on Hg, As, and B. These are the trace contaminants of major concern and procedures for characterizing the chemical species of Hg and As have been established. For Hg, soils and vegetation would be examined for Hg^0, Hg(II) compounds, and the highly toxic methyl mercury. For As, soils and vegetation would be examined for inorganic As(III) and As(V) and the methylated organic forms, methylarsenic acid and dimethylarsenic acid. (A relatively high percentage of the arsenic found in nature is generally in organic forms.) Some developmental work will be required to evaluate the speciation of boron, commonly postulated to occur as boric acid when elevated.

The large brine holding pond created at Cerro Prieto would serve as a unique natural laboratory to study the alterations in chemical species of geothermal contaminants released to surface waters. Substantial sediment deposits exist at this pond and surprisingly enough, the pond is teeming with zooplankton. Undoubtedly, these organisms are accumulating elevated levels of many trace elements such as As, B, Se, and Hg. The concentrations and chemical forms of these elements would be determined in the biota and sediments from this holding pond to determine if chemical changes are occurring to transform these elements into more, or less, toxic forms.

CONCLUSION

Geothermal steam and hot-water resources can provide a meaningful portion of the United States and world energy needs if some important environmental issues can be resolved. This work study has identified seven projects to address the most significant and scientifically deficient of those issues. Each project is designed to provide generic environmental information. Since they require vast varieties of skills and resources, each project has been assigned to a national laboratory having the necessary expertise to complete the tasks in that project (see Appendix C). The work study itself is designed around a generic model rather than site specific cases. Successful completion of this work study should provide the data and methodologies needed to resolve the most critical environmental issues related to the development of geothermal energy.

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APPENDIX A

Publications Relevant to This Study

The publications have been grouped and listed in reverse chronological order. Only rarely is a publication dated before 1977 listed. The groups are

1. Assessments and Workshops
2. General Information
3. Air Quality and Tranpsort
4. Water Quality and Modeling
5. Soils
6. Human Health
7. Ecology and Animals
8. Pollutant Source Characterization
9. Waste Disposal and Control Technology

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Pollutant Source Characterization

- Battelle Pacific Northwest Laboratory. A series of papers (with the approximate titles below) to appear in the literature and authored by one or more of the following. D. E. Robertson, J. D. Ludwick, C. L. Wilkerson, J. S. Fruchter, C. L. Crecelius, J. C. Evans, K. H. Abel, and K. B. Olsen.

  "Environmental chemistry of mercury released in geothermal fluids,"

  "Chemical impacts from geothermal energy development,"

  "Natural geothermal emissions from hot springs and fumaroles in the Mono-Long Valley KGRA,"

  "A comparison of chemical emissions in effluents at ten geothermal resource areas in the western US,"

  "Analysis of well gases from areas of geothermal power potential,"

  "Characterizing emissions of gases and trace elements for geothermal power plant cooling towers,"

  "Mass Balances of Gases and Trace Elements Through a Modern, H_2S Abated Geothermal Power Plant,"

  "Correlation of Hydrogen Sulfide and Mercury Vapor Concentrations in Ambient Air at the Geysers Geothermal Development,"

  "Accumulation of Mercury, Boron, Arsenic and Other Trace Elements in Soils in the Vicinity of Geothermal Power Plants at The Geysers."

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Waste Disposal and Control Technology

- Morris, William and Hill, John, "Environmental Control Technology," in "An Assessment of Geothermal Development in The Imperial Valley of California," Vol. 2, DOE/EV-0092, July 1980.
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APPENDIX B

Current and Recent Research on Geothermal/Hydrothermal Problems

The research programs listed here were obtained from the Smithsonian Science Information Exchange data base and have been separated into the following groups.

1. General Assessment
2. Data Bases
3. Health Effects (Human/Animal)
4. Aquatic Effects
5. Plant Effects
6. Soils
7. Water Quality
8. Spills
9. Hydrology
10. Air Quality
11. Air Transport
12. Seismic
13. Socioeconomic
14. Methods/Instruments
15. Control Technology

SOME CURRENT AND RECENT RESEARCH PROGRAMS IN GEO/HYDROTHERMAL DEVELOPMENT*

Category	Investigator(s)	Organization	Title	Period	Funding Agency
General Assessment	• Anspaugh, L.	LLNL	Technology Assessments and EDP's	10/78–	DOE (Wash/OTI)
	• Anspurgh, L.	LLNL	Integrated Assessments to Support High Priority Geothermal Development Areas	0/78–	DOE (Wash/DTOIA)
	• Bernstein, H.	Hittman Assoc. Inc.	Quick Response, Policy, Environmental and Economic Analysis Support	1/78–	DOE (Wash)
	• Craig, R.B.; Cushman, R.M.; Oakes, K.M.; Moran, M.S.; Suter, G.W.	ORNL	Environmental Analysis of Geothermal Energy	3/78–	DOE (Wash/BES)
	• Edwards, W.H.; Allan, J.S.	U of Utah	Raft River Geothermal Studies	7/75–	DOE ((Idaho)
	• Grether, D.F.; Siri, W.	LBL	Environmental Impacts of Geothermal and Solar Energy	0/78–	DOE (Wash/DBER)
	• Kalagher, R.	Mitre Corp	Environmental Impacts Analysis of the National Energy RD and D Plan	0/78–	DOE (Wash/OEPA)
	• Moody, M.	LBL	Geothermal Loan Guarantee Program Assessment of Environmental Control Environmental Control	4/77–	DOE (Wash/OECO)
	• Musgrave, C.	U of Idaho	Raft River Geothermal Ecology	0/78–	DOE (Chicago)
	• Phelps, P.A.	Bechtel Nat. Inc.	Geothermal Power Plant Studies	0/77–0/81	DOE (Wash)
	• Phelps, P.L.	LLNL	Imperial Valley Environmental Project Assessment of Environmental Control	4/77–	DOE (Wash.DECT)
	• Phelps, P.L.	LLNL	Geothermal Loan Guarantee Program Assessment of Environmental Control	4/77–	DOE (Wash/DECT)
	• Phelps, P.L.	LLNL	IVEP Preplanning Appraisals in KGRAs	0/78–	DOE (Wash/DBER)
	• Selby, J.M.	BPNL	Identification of EHH Standards for Geothermal Programs	0/78–	DOE (Wash/DOES)
	• Shinn, J.	LLNL	Geothermal Studies (Geysers)	0/80–	DOE (Wash/DBER)
	• Snoeberger, D.F.	LLNL	Assessment of Geothermal Loan Guaranty Applications for Environmental and Safety Concerns	0/78–	DOE (Wash/DECT)
	• Williams, J.M.	Los Alamos NL	Hydrothermal Environmental Assessment	0/80–	DOE (Wash/OE)
	• Unknown	Union Oil Co. of NM	Geothermal Demonstration Power Plant	9/78–	DOE (Wash)
	• Unknown	LLNL	Management and Planning Support for Geothermal Solar Environmental Projects	0/78–	DOE (Wash/DTOIA)
Data Bases	• Lederer, C.M.	LBL	National Geothermal Information II	6/74–	DOE (Wash/ORA)
	• Phillips, S.L.	LBL	National Geothermal Information Resource	7/75–	DOE (Wash/OHER)

Category	Investigator(s)	Organization	Title	Period	Funding Agency
Health Effects (Human/Animal)	• Anspaugh, L.R.	LLNL	IVEP–Health Effects	10/76–5/80	DOE (Wash/OHER)
	• Anspaugh, L.R.	LLNL	Health and Environmental Assessment of Energy Technologies	10/80–	DOE (Wash/OE)
	• Ischinger, L.	DOE/Fish & Wildlife/Colorado	Wetlands Disposal of	1/79–6/80	EPA (Cincinnati ORD)
	• Renne, R.A.	BPNL	Toxic Effects of Geothermal Effluents Geothermal Waste Water	10/77–	DOE (Wash/OE)
Aquatic Effects	• Klontz, G.W.	U of Idaho	Fish Culture Using Geothermal Water	7/78–9/79	Idaho State Gov.
	• Leland, H.V.	USGS/Menlo Park	Effects of Toxic Substances Related to Expanding Energy Technologies on Aquatic Ecosystems	6/75–	USGS (Menlo Park)
	• Resh, V.H.	U of Calif/Berkeley	The Influence of Geochemical Origin and Drought Conditions on Aquatic Biota of the KGRA of California	0/79–12/81	DOE (Wash/OWRT)
	• Resh, V.H.	U of Calif/Berkeley	Biological Indicators of Environmental Quality in California Lakes and Streams	3/76–12/80	DOA (Berkeley)
Plant Effects	• Roger, L.E.	BPNL	Terrestrial Effects	10/77–	DOE (Wash/OHER)
	• Shinn, J.H.	LLNL	Geothermal Studies – Environmental Effects	7/75–	DOE (Wash/DBER)
	• Shinn, J.H.	LLNL	Ecosystem Quality	7/76–9/80	DOE (Wash/DBER)
	• Thompson, C.R.	U of Calif/Riverside	Effects of H_2S on Vegetation	9/78–9/79	DOE (Wash/OHER)
	• Thompson, J.H.	U of Calif/Los Angeles	Effects of Atmospheric H_2S on Vegetation	0/80–	DOE (Wash/OHER)
Soils	• Alexander, G.	U of Calif/Los Angeles	Development of a Strategy for Monitoring Contamination of Plants, Animals, and Soils by Studying Areas in Roosevelt Hot Springs, Utah	11/78–12/79	EPA (Las Vegas/ORD)
	• Doner, H.E.	U of Calif/Berkeley	Trace Element Distribution and Mobility in Soils. Cu, N, and Cd	4/76–6/81	DOA (Berkeley)
	• Thoedsson, T.	Swedish U of Agricultural Sciences	Ecological Effects of Extraction of Geothermal Energy	3/78–12/81	Swedish Govt
	• Wiersma, G.B.	EPA/Las Vegas	Development of a Strategy for Monitoring Contamination of Plants, Animals, and Soils by Studying Areas in Roosevelt, Hot Springs, Utah	6/76–7/80	EPA (Las/Vegas ORD)
Water Quality	• Chen, C.W.	Tetra Tech Inc	Contamination of Ground Water in Geothermal Development	11/77–3/79	EPA (Cincinnati/ORD)
	• Crow, N.B.	LLNL	IVEP Geothermal – Water Quality	0/78–	DOE (Wash/DBER)
	• Jenne, E.A.	USGS/Menlo Park	Trace Element Reactions & Downstream Attenuation Processes in Waters of Geothermal Origin	3/74–	USGS (Menlo Park)

Category	Investigator(s)	Organization	Title	Period	Funding Agency
	• Kowalski, B.R.	U of Washington	Trace Element Characterization and Speciation in Geothermal Effluent	0/79–	DOE (Wash/OHER)
	• Kresse, F.C.; Weiss, R.B.	Harding Lawson Assoc.	Monitoring Changes in Groundwater Quality as a Result of Geothermal Development, Conversion, and Waste Disposal	5/78–10/79	EPA (Las Vegas/ORD)
	• Pimentel, K.D.	LLNL	IVEP Geothermal – Water Quality	10/76–	DOE (Wash/OHER)
	• Rea, K.H.	Los Alamos NL	Ecological Investigation of Dry Geothermal Energy Demonstration	1/76–	DOE (Wash/OHER)
Spills	• Sung, R.D.;Zuckerman, I.	Thompson Ramo Woodridge, Inc	Containment of Geothermal Brines	9/77–3/79	EPA (Cincinnati/ORD)
Hydrology	• Albright, N.;Chorini, A.; Greenbaum, F.A..Concus, P.	LBL	Analytical and Numerical Methods	0/80–	DOE (Wash/OER)
	• Brogan, G.C.	Woodward & Clyde Consultants	Faults and Occurrences of Geothermal Anomalies	9/78–	USGS (Reston)
	• Caudle, B.H.; Sun, J.	U of Texas (Austin)	Modeling Injection and Aquifer Pressure for Geothermal Disposal Wells	0/79–	U of Texas
	• Ershaghi, I.	USC (Los Angeles)	Formation Evaluation in Liquid–Dominated Geothermal Reservoirs	12/76–9/79	DOE (Wash)
	• Faust, C.R.	USGS (Reston)	Analysis of Mechnical and Thermal Water–Rock Interactions in Fractured Hydrogeologic Systems	19/77–9/80	USGS (Reston)
	• Fletcher, J.F.	Westinghouse Hanford Co	Water Use Information System	1/76–	DOE (Wash/OPE)
	• Lehr, J.H.	National Water Well Assoc	Computer Simulation to Assess the Environmental Impact of Residential Ground–Water Heat Pump Utilization	8/79–8/81	EPA (Oklahoma/DRD)
	• Maclay, R.W.	USGS (San Antonio)	Limestone Hydrology Research – San Antonio Area	6/70–	USGS (San Antonio)
	• Mariner, R.H.	USGS (Menlo Park)	Chemical and Isotope Studies of Thermal Waters of the Western US	10/78–	USGS (Menlo Park)
	• Mercer, J.W.	USGS (Reston)	Investigation of Energy Transport and Associated Mass Transport in Porous Media Involving Both Single and Multiphase Flow Conditions	10/77–9/82	USGS (Reston)
	• Mercer, J.W.	USGS (Reston)	Mathematical Modeling of Geothermal Systems	7/72–	USGS (Reston)
	• Montgomery, W.D.	Cal Tech (Pasadena)	Water and Geothermal Assessment	0/78–	DOE (Wash/DTOIA)
	• Muffler, L.J.	USGS (Menlo Park)	Geothermal Resource Assessment	10/76–	USGS (Reston)
	• Ogata, A.	USGS (Menlo Park)	Transport Process in Fluid Flow	7/69–	USGS (Menlo Park)
	• Pearson, F.J.	USGS (Reston)	Isotope Hydrology	7/56–	USGS (Reston)
	• Riney, T.D.	Systems Science & Software Inc	Integrated Model of the Shallow and Deep Hydrothermal Systems in the East Mesa Area, Imperial Valley, CA	9/78–	USGS (Reston)

Category	Investigator(s)	Organization	Title	Period	Funding Agency
	• Sorey, M.L.	USGS (Menlo Park)	Numerical Modeling of Liquid Geothermal Systems	7/72–	USGS (Menlo Park)
	• Tiah, D.	U of Oklahoma (Norman)	Engineering Research Initiation – Fluid Flow in Heterogeneous Porous Media	4/78–3/80	NSF (Wash)
	• Young, H.W.	USGS (Boise)	Geothermal Investigations in Idaho	4/74–	USGS (Boise)
Air Quality	• Gilmore, D.B.	EOA (Las Vegas)	Monitoring Guidelines for H_2S and Non–Condensible Hazardous Gases	0/79–	EPA (Las Vegas)
	• Gudiksen, P.H.	LLNL	Air Quality Impacts of Geothermal Development in California	10/77–	DOE (Wash/OHER)
	• Gudiksen, P.H.	LLNL	IVEP Geothermal – Air Quality	10/77–	DOE (Wash/OHER)
	• Robertson, D.E.	BPNL	Heavy Metal and Noxious Gas Emissions	9/77–12/79	EPA Las Vegas/ORD)
	• Woodward, R.N.	Northrup Corp	Monitoring Guidelines for H_2S and Non–Condensible Hazardous Gases	9/77–12/79	EPA (Las Vegas/ORD)
Air Transport	• Dickerson	LLNL	Pollutant Transport in Complex Terrain	10/78–	DOE (Wash/OHER)
	• Rankin, R.L.	Arizona State U	The Effects of Topography, Albedo and Thermal Inertia Variations on the Generation of Mesolale Martian Wind Patterns	7/79–12/80	NASA (Wash/OSS)
	• Schuster, K.	Los Alamos NL	Plume Transport and Diffusion	10/78–	DOE (Wash/OHER)
	• Slinn, W.G.	BPNL	Theoretical Air Pollution Studies and Applications	10/74–	DOE (Wash/OE)
	• Wagner, K.K.	U of California (Davis)	Mesoscale Wind Pattern Analysis and Modeling	7/76–6/81	DOA (Berkeley/CRO)
Seismic	• Bufe, C.G.	USGS (Menlo Park)	Seismic Monitoring at the Geysers Geothermal Field	7/77–	DOE (Wash/DGE)
	• Crow, N.B.	LLNL	IVEP Geothermal Subsidence and Seismicity	11/75–	USGS (Sacramento)
	• Lofgren, B.E.	USGS (Sacramento)	Subsidence and Crustal–Strain Research in Mexicali Valley Geothermal Area, CA	10/77–3/80	USGS (Sacramento)
	• Page, E.A.	ENSCO Inc	Special Geothermal Ground Noise Experiment	7/78–	USGS (Reston)
	• Rudnicki, J.W.; Johnson, R.E.	U of Illinois (Urbana)	Physical Processes of Subsidence in Geothermal Systems	6/79–12/79	DOE (Wash)
	• Ward, R.A.	U of Texas (Dallas)	Evaluation of Geothermal Systems Using Telescience	3/77–	USGS (Reston)
	• Weaver, C.S.	USGS (Menlo Park)	Geothermal Tectonic Seismic Studies	10/77–	USGS (Menlo Park)

Category	Investigator(s)	Organization	Title	Period	Funding Agency
Socioeconomic	• Mendelsohn, M.L.; Morimoto, E.	LLNL	IVEP Geothermal – Socioeconomic Assessment	0/78–	DOE (Wash)
Methods/Instruments	• Danielson, M.J.; Jensen, G.A.	BPNL	Chemical Control and Monitoring Instrumentation Subcontract	10/78–9/82	DOE (Wash/ORA)
	• Hess, J.W.	U of Nevada (Reno)	Groundwater Monitoring for Geothermal Development	1/79–1/83	EPA (Cincinnati/ORD)
	• Hess, J.W.	U of Nevada (Reno)	Geothermal Impact – A Systems Approach to Monitoring Environmental Impacts from Development, Conversion, and Waste Disposal	4/79–10/83	EPA (Las Vegas/ORD)
	• Wogman, N.A.	BPNL	Environmental Pollution Analysis, Instruments and Methods Development	10/76–	DOE (Wash/OHER)
Control Technology	• Deferling	BPNL	Plan for Geothermal Liquid Waste Disposal Program	0/79–	DOE (Wash/OHER)
	• Gorman, P.	Midwest Research Inst	Evaluation of H_2S Control Technology for Geothermal Energy Sources	0/78–	DOE (Wash/DECT)
	• Phelps, P.	LLNL	Assessment of Environmental Control Technologies for KGRAs	0/80–	DOE (Wash/OECO)
	• Sung, R.D.	Thompson Ramo Woodridge Inc	Costs of Geothermal Pollution Control	9/77–	EPA (Cincinnati/ORD)

*From the Smithsonian Scientific Information Exchange's Current Research database on the Dialog Information Services' electronic database system.

APPENDIX C

Vitae of Scientific Authors

The personnel given here would be responsible for the conduct of the various programs described in this study. A few pertinent publications are also given for each.

Name	Laboratory	Area of Responsibility
Anspaugh, Lynn R.	Livermore	Human Health Responses
Barr, Sumner	Los Alamos	Air Transport of Pollutants
Robertson, David (Dave) E.	Battelle, PNW	Pollutant Source Characterization
Shinn, Joseph (Joe) H.	Livermore	Aqueous and Terrestrial Deposition and Impact of Pollutants
White, Gary C.	Los Alamos	Wildlife Habitat Utilization
Williams, Joel M.	Los Alamos	Aqueous and Terrestrial Impacts and Hydrology

HUMAN HEALTH RESPONSES

Lynn R. Anspaugh
Lawrence Livermore National Laboratory

Education

B.A.	Physics, Nebraska Wesleylan University	1959
M.S.	Bioradiology, University of California, Berkeley	1961
Ph.D.	Biophysics, University of California, Berkeley	1963

Experience

1963 - Present	Staff Member Lawrence Livermore National Laboratory
1974 - 1975	Group Leader, Applied Environmental Sciences Lawrence Livermore National Laboratory
1975 - 1980	Project Leader, Imperial Valley Environmental Project Lawrence Livermore National Laboratory
1976 - Present	Section Leader, Analysis and Assessment Lawrence Livermore National Laboratory

Major Research Interests

- Aeolian resuspension of radionuclides
- Public health implications of the utilization of geothermal energy

Tasks Undertaken at Lawrence Livermore National Laboratory

- Analysis of chemical elements in human tissue
- Assessment of radiological hazards from Projects Ketch and Rulison
- Development of radiation dose model for THO
- Experiments on the resuspension of plutonium
- Planning and direction of the Imperial Valley Environmental Project

Work in Progress

- Calculation of dose from internal emitters to residents downwind from the Nevada Test Site

- Preparation of Health and Environmental Effects Document for Geothermal energy

Recent Relevant Publications

L. Anspaugh, "Human Health Impacts," in "Workshops to Rate and Assign Air and Water Issues for Hydrothermal Energy Development," Los Alamos Scientific Laboratory report LA-8613-C, 1980.

L. R. Anspaugh and J. L. Hahn, "Human Health Implications of Geothermal Energy," in Health Implications of New Energy Technologies, W.N. Rom and V. E. Archer, eds. (Ann Arbor Science Publishers, Inc., Ann Arbor, MI) 1980; also Livermore report UCRL-83382.

L. Anspaugh and P. Leitner, "Health and Safety Concerns," in "An Assessment of Geothermal Development in the Imperial Valley of California," US DOE/EV-0092, 1980.

Paul L. Phelps, Donald L. Ermak, Lynn R. Anspaugh, etal., "Preliminary Environmental Assessments of Known Geothermal Resource Area in the United States," Geothermal Resource Council Transactions, Vol. 2, 1978.

L. R. Anspaugh, "Final Report on the Investigation of the Impact of the Release of ^{222}Rn, Its Daughters, and Precursors at The Geysers Geothermal Field and Surrounding Area," Livermore report, 1978.

L. R. Anspaugh, "The Geothermal Environmental Overview Project," Livermore report UCID-17632, 1977.

AIR TRANSPORT OF POLLUTANTS

Sumner Barr
Los Alamos National Laboratory

Education

B.S.	Chemical Engineering, University of Massachusetts	1960
M.S.	Meteorology, Massachusetts Institute of Technology	1965
Ph.D.	Meteorology, University of Utah	1969

Experience

1960 - 1963	Weather Officer United States Air Force
1964 - 1969	Scientist GCA Corporation, Salt Lake City, UT
1972 - Present	Staff Member Los Alamos National Laboratory, Los Alamos, NM
1977 - Present	Group Leader, Group ESS-7 Los Alamos National Laboratory, Los Alamos, NM

Major Research Interest

- Boundary layer meteorology as influenced by terrain irregularities
- Atmospheric turbulence and diffusion
- Dynamic meteorology

Tasks Undertaken at Los Alamos National Laboratory

- Precipitation scavenging of weapon debris
- Safety analyses on Los Alamos National Laboratory facilities
- Generalized studies of atmospheric transport and dispersion in complex terrain
- Develop concepts and techniques for tracer applications
- Climate dynamics

Work in Progress

- Complex terrain transport estimation methods development and application to geothermal, oil shale, uranium, and coal technologies
- Tracer system testing and application
- Define practical problems of climate change, including case studies of volcanic plumes
- Copreparation of chapter on atmospheric diffusion modeling for DOE monograph "Meteorology and Power Production"

Recent Relevant Publications

S. Barr and T. G. Kyle, "Pollutant Transport and Dispersion," in "Workshops to Rate and Assign Air and Water Issues for Hydrothermal Energy Development," Los Alamos Scientific Laboratory report LA-8613-C, 1980.

S. Barr et al., "Workshop on Research Needs for Atmospheric Transport and Diffusion in Complex Terrain, September 28-10, 1976, Albuquerque, NM," CONF-7609160, September 1976.

S. Barr and S. K. Wilson, "Meteorological Analysis for Fenton Hill," draft LA-MS.

S. Barr, "Meteorological Aspects of Air Quality in Oil Shale Development," working paper.

S. Barr and T. Gedayloo, "Proceedings of the Atmospheric Tracers and Tracer Application Workshop, held at LASL, May 23-24, 1979," Los Alamos Scientific Laboratory report LA-8144-C, 1979.

T. Gedayloo, W. E. Clements, S. Barr, and J. A. Archuleta, "Nocturnal Drainage Wind Characteristics in Two Converging Air Sheds," Los Alamos Scientific Laboratory document LA-UR-80-805, Second Joint conference on applications of Air Pollution Meteorology, American Meteorological Society, New Orleans, LA, March 24-27, 1980.

POLLUTANT SOURCE CHARACTERIZATION

David E. Robertson
Battelle, Pacific Northwest Laboratories

Education

B.S.	Chemistry, Brigham Young University	1961
	Hanford Graduate Center, Richland, Washington	1961- 1963

Experience

1961 - 1965	Chemist General Electric Company, Richland, Washington
1965 - 1971	Research Scientist Battelle, Pacific Northwest Laboratories
1971 - 1976	Senior Research Scientist Battelle, Pacific Northwest Laboratories
1976 - Present	Staff Scientist Battelle, Pacific Northwest Laboratories

Major Research Interest

- Environmental chemistry and geochemistry
- Trace element and gas measurements
- Geothermal energy environmental impact assessment
- Radiological evaluation of nuclear power industry

Tasks Undertaken at Battelle, Pacific Northwest Laboratories

- Design and development of ultra-sensitive gamma-ray spectrometry instrumentation and radioanalytical procedures
- Development of sensitive and selective methods of trace element analyses
- Marine geochemistry and radioecology studies
- Radioecology studies of fresh water environs
- Geothermal environmental studies and source term characterization
- Radiological environmental studies around nuclear power plants
- Decommissioning studies of nuclear power plants
- Low-level radioactive-waste groundwater migration studies

Work in Progress

- Assisting in developing a geothermal sampling and analytical methods manual for the US EPA.
- Publication of geothermal environmental research papers
- Nuclear power plant decommissioning studies
- Studies of radionuclide migration in groundwaters from low-level waste disposal and burial sites

Recent Relevant Publications

D. E. Robertson et al., "Mass Balances of Gases and Trace Elements Through a Modern, H_2S Abated Geothermal Power Plant," publication in progress, 1981.

D. E. Robertson et al., "Correlation of Hydrogen Sulfide and Mercury Vapor Concentrations in Ambient Air at The Geysers Geothermal Development," publication in progress, 1981.

D. E. Robertson et al., "Chemical Characterization of Gases and Volatile Heavy Metals in Geothermal Effluents," Geotherm. Resour. Counc. Trans. 2, 1978.

D. E. Robertson, "Heavy Metal Emissions from Geothermal Power Plants," in Proceedings of the Second Workshop on Sampling Geothermal Effluents, EPA-600/7-78-121, 1977.

J. D. Ludwick, D. E. Robertson et al., "Characterizing Emissions of Gases and Trace elements from Geothermal Power Plant Cooling Towers," publication in progress, 1981.

C. L. Wilkerson, D. E. Robertson, and K. B. Olsen, "Accumulation of Mercury, Boron, Arsenic and Other Trace elements in Soils in the Vicinity of Geothermal Power Plants at The Geysers," publication in progress, 1981.

AQUEOUS AND TERRESTRIAL DEPOSITION AND IMPACT OF POLLUTANTS

Joseph H. Shinn
Lawrence Livermore National Laboratory

Education

B.S.	Biology (Soils minor), Delaware Valley College	1959
M.S.	Micrometeorology (Plant Physiology minor), Cornell University	1962
Ph.D.	Meteorology (Plant Ecology minor), University of Wisconsin	1971

Experience

1959 - 1962	Physical Sciences Aide, USDA Microclimate Investigation Ithaca, New York
1962 - 1967	Project Assistant, Department of Meteorology, University of Wisconsin
1967 - 1970	Research Meteorologist, US Army Electronics Command, Atmospheric Sciences Laboratory, Ft. Huachuca, Arizona
1970 - 1973	Research Meteorologist, US Army Electronics Command, Atmospheric Sciences Laboratory, White Sands Missile Range New Mexico
1973 - Present	Meteorologist, Environmental Sciences Division, Lawrence Livermore National Laboratory, Livermore, California

Major Research Interests

- Processes of deposition of gases and particles
- Terrestrial systems ecology
- Boundary layer meteorology
- Atmospheric turbulence and diffusion

Tasks Undertaken at Lawrence Livermore National Laboratory

- Resuspension of plutonium-contaminated soil particles
- Air pollution effects studies
- Ecological problem of geothermal energy
- Meteorological tower studies of boundary layer scaling parameters
- Turbulence in heavy gas mixtures

Work in Progress

- Comparative plutonium fluxes between sites in Bikini, Nevada, and South Carolina
- Enhancement factors in pulmonary deposition of plutonium aeorsols
- Simulation of a marine boundary layer at a shallow lake in a desert
- Entrainment of air into methane clouds during LNG spills at China Lake

Recent Relevant Publications

J. H. Shinn and R. R. Ireland, "Ecology Problems Associated with Geothermal Development in California," Livermore preprint UCRL-83941, 1980.

J. H. Shinn, "Environmental Impacts," in "Workshops to Rate and Assign Air and Water Issues for Hydrothermal Energy Development," Los Alamos Scientific Laboratory report LA-8613-C, 1980.

J. H. Shinn et al., "Investigations of Ecosystems Impacts from Geothermal Development in Imperial Valley, California," Geotherm. Resour. Counc. Trans. 3, 651-654, 1979.

J. H. Shinn et al., "Potential Effects of Geothermal Development on Imperial Valley Ecosystems, Proceedings of the First Workshop on Integrated Assessment of Ecosystem Quality," Livermore report UCRL-52196, 1976.

J. H. Shinn et al., "Exposure of Field Grown Lettuce to Geothermal Air Pollution-Photosynthetic and Stomated Responses," J. Environ. Sci. and Heath, A11, 1976.

WILDLIFE HABITAT UTILIZATION

Gary C. White
Los Alamos National Laboratory

Education

B.S.	Fisheries and Wildlife, Iowa State University	1970
M.S.	Wildlife Biology, University of Maine at Orono	1972
Ph.D.	Zoology, The Ohio State University	1976

Experience

1976 - 1977 Post-doctoral research at Utah State University on environmental impact of oil shale development

1977 - Present Staff Member
Los Alamos National Laboratory
Los Alamos, NM

Major Research Interest

- Animal abundance estimation
- Analysis of biotelemetry data
- Transport of contaminants in the environment

Tasks Undertaken at Los Alamos National Laboratory

- Transuranic transport in southwestern ecosystems
- Deer biotelemetry at Los Alamos National Environmental Research Park
- Statistical analysis of pellet group data to monitor big game population trends
- Application of Kriging to contaminant transport problems

Work in Progress

- Impact of Oil Shale Development on the Piceance Mule Deer Herd
- Statistical Analysis of Biotelemetry data

Recent Relevant Reports

G. White, "Biotelemetry Studies on Elk - A Progress Report," Los Alamos National Laboratory report LA-8529-NERP, 1981.

G. C. White and J. Lissoway, "Research Plan for Elk in the Eastern Jemez Mountains," Los Alamos Scientific Laboratory report LA-8079-MS, 1980.

G. C. White, "Computer Generated Movies to Display Biotelemetry Data," Proc. Second Int. Con. on Wildlife Biotelemetry, University of Wyoming, Laramie, Wyoming, 1979.

Gary C. White and Lester E. Eberhardt, "Statistical Analysis of Deer and Elk Pellet-Group Data," J. Wildl. Manage, 44(1), 1980.

L. E. Eberhardt and G. C. White, "Movements of Mule Deer on the Los Alamos National Environmental Research Park," Los Alamos report LA-7742, 1979.

D. L. Otis, K. P. Burnham, G. C. White, and D. R. Anderson, "Statistical inference from capture data on closed animal populations," Wildl. Monogr. No. 62, 1978.

AQUEOUS AND TERRESTRIAL IMPACTS AND HYDROLOGY

Joel M. Williams, Jr.
Los Alamos National Laboratory
Environmental Science Group
LS-6, MS-495
Los Alamos, NM 87545

Education

B.S.	Chemistry (Mathematics minor), College of William and Mary	1962
Ph.D.	Physical Organic Chemistry, Northwestern University	1966
Postdoc.	NSF Fellow, University of Minnesota	1967

Experience

1967 - 1968	Assistant Professor of General Chemistry, University of Minnesota
1968 - 1972	Research Chemist, E. I. duPont, Waynesboro, VA: polymers and textile chemistry
1972 - Present	Staff Member, Los Alamos National Laboratory, Los Alamos, NM.

Major Research Interest

- Mechanisms of pollutant production and transport in water and soils.
- Control technologies for waste disposal processes.
- Waste and materials characterizations.
- Computerized data storage, evaluation, and display.

Relevant Tasks Undertaken at Los Alamos National Laboratory

- Work study development for geothermal energy environmental issues.
- Control technologies for and definition of the aqueous pollution from coal cleaning wastes.
- Characterization and leaching of retorted oil shale.

Work in Progress

- Study of the environmental effects of acute brine spills from hydrothermal energy developments.
- Evaluation of hydrological aspects of hydrothermal energy.
- Characterization and treatment of uranium mill tailings for safe disposal.

Recent Relevant Publications

Joel M. Williams and E. M. Wewerka, "Workshops to Rate and Assign Air and Water Issues for Hydrothermal Energy Development," Los Alamos Scientific Laboratory report LA-8613-C, 1980.

Joel M. Williams, "Hydrology for Baca Location #1 - A Discernment of Opposing Reports" (draft).

Joel M. Williams et al., "Trace Element Characterization of Coal Wastes - 4th Annual Progress Report," Los Alamos Scientific Laboratory report LA-8275-PR, also EPA - 600/7-81-073, 1981.

Joel M. Williams et al., "Coal Preparation Waste Micromineralogy," Los Alamos Scientific Laboratory report LA-8474-MS, 1980.

Joel M. Williams, etal., "Removal of Radioactivity and Mineral Values from Uranium Mill Tailings," Proceedings on Uranium Mill Tailings Management, Fort Collins, CO, October 26-27, 1981.

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