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PROPOSAL FOR A STUDY OF THE HEALTH HAZARDS OF

GAS EMISSIONS FROM

POAS VOLCANO, COSTA RICA

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Costa Rica

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INTRODUCTION

HEALTH HAZARDS OF VOLCANIC GASES

In Central America, volcanoes and earthquakes pose major environmental threats to populations. In particular, degassing volcanoes may adversely affect the health of local inhabitants. For example the recent gas emission crisis at Masaya, Nicaragua, which began in 1979, exposed thousands of people to hazardous levels of SO_2 and sulphate aerosols downwind (1,2). During different phases of their activity other volcanoes may emit toxic plumes into populated areas, e.g. San Cristobal, Nicaragua.

Volcanic gases typically contain water vapour, carbon dioxide, sulphur dioxide, hydrogen sulphide, hydrogen chloride, hydrogen fluoride, and carbon monoxide. SO_2 is the main irritant gas released from volcanoes and is the key marker gas for measuring exposure and ascertaining the air pollution risk in populated areas. In contrast, H_2S poses the greatest danger in crater areas where relatively low concentrations (500-1000ppm) can be lethal. Synergistic effects of mixtures of volcanic gases should be considered. Thus a guideline value for SO_2 exposure in populations should be set below those promulgated by official bodies in order to provide an ample safety margin. HCl and HF are highly soluble in water and are readily removed from the plume by precipitation and dry deposition on to soil and vegetation, though both could adhere to the surface of fine dust particles; levels of these gases could fall by 50% over a distance of 30-40km. Unlike SO_2, H_2S is not a significant respiratory tract irritant at low concentrations, but can be a nuisance as its offensive odour is detectable below 1ppm.

On one day in March 1991 the levels of the main gases in the plume at Poas were measured at the crater rim (Baxter P., personal communication). The results were SO_2 4ppm, HCl 2ppm and H_2S 2ppm. The mean SO_2 level measured over several days using passive diffusion tubes at a farm 10km from the volcano was 0.14ppm which exceeded WHO guidelines for SO_2 (24 hours: 0.04ppm; one year: 0.02ppm). The representativeness of these results is unknown.

In industrial air pollution the conversion of SO_2 to soluble sulphates is catalysed by photo-oxidants. In volcanic plumes the presence of various cations in solution in the aerosols, e.g. iron, may catalyse this conversion instead. Recent evidence suggests that it is the hydrogen ion that is the key factor in exacerbating respiratory disease in industrial air pollution episodes (3).

The incidence of asthma is rising in European countries and North America. The reasons are obscure, but could be related to air pollution, in particular the presence of acid aerosols in urban air (3). Community studies of the incidence of asthma are complex undertakings but this study will adhere to the methodology of the European Community Respiratory Health Study which is currently in progress and involving the collaboration of the Department of Public Health Medicine, St Thomas's Hospital, London, who are advising on this proposal.

POAS

Poas, a composite basaltic-andesite cone situated on the Cordillera Central, of Costa Rica, rises 1300m above its base at 1400m. Historically it has been in a state of nearly continuous mild activity. The active crater is roughly circular with a diameter of about 1100m and a crater lake has existed since 1965. In the early 1970s minimal fumarole activity was observable at Poas, but in 1977/78 several geyser-explosions occurred in the lake, and by 1980 gas emissions had dramatically increased. At that time a team led by the U.S. volcanologist Dr R. Stoiber used COSPEC to estimate SO_2 flux, which was in the order of 500t per day (2), and Stoiber predicted that this large emission could have health consequences to populations downwind. No reports of health problems were available at that time, but the concept that Poas could pose a health hazard from its emissions was not fully appreciated by the medical community until 1987 or later. It is therefore possible that the health impact could have preceded the recent crisis but gone unrecognised.

Until 1986 the heat input from the presumed shallow magma body was balanced by the heat output from the fumaroles and crater lake, with degassing occurring through the central vent beneath the lake. Since 1987, gas emissions from Poas volcano have apparently increased and have been reported to affect vegetation and cause health problems, e.g. bronchospasm, respiratory infections, conjunctivitis, dermatitis, gastro-intestinal upsets and headache, in the populated areas downwind which are subjected to repeated fumigation because of the constant prevailing winds. During this period the hot crater lake has undergone an annual cycle in which its level rises and falls with the wet and dry seasons; in the dry season it becomes strongly acidic because of enhanced evaporation and concentration of anions, and it is during this period that most of the health complaints are reported. Therefore, in addition to gas from the crater fumaroles the plume may contain copious amounts of concentrated acid aerosol from the lake which would greatly increase the health hazard from inhaling contaminated air (4,5). In addition, the impacted area has suffered extensive damage to vegetation, and considerable losses to the coffee, sugar cane and cut-flower crops; ill-health effects have also been reported in cattle. The changes at Poas probably reflect a dramatic increase in power input consistent with the injection of shallow magma beneath the crater lake and which may have coincided with an increase in the flux of gases and aerosols since 1986 (6-9).

Geophysical data obtained by the Open University, U.K. (8), and other observations indicate that the present crisis reached a peak in 1989 and has declined slightly since. However, health problems continued to arise in 1991 and the future activity of Poas cannot be predicted. In view of this, the earliest opportunity should be taken to evaluate the present health impact in relation to the volcano's activity so that an understanding of the mechanisms involved can be obtained to assist in the future monitoring of the volcano. At least three explanations can be proposed. When the lake level is high gases or aerosols may be scrubbed out, thereby reducing the toxic load of the plume. When the lake level falls the water becomes a concentrated mixture of sulphuric and hydrochloric acids (10), and this may fume into the venting gases and increase the load of fine, concentrated acid aerosols that could be a potent irritant to the respiratory system in populations living at considerable distances downwind. A third stage is when the lake has dried out, when the gases vent directly into the air. Other possible factors requiring study are the outputs of gases and solid particulates, and meteorological variables, e.g. humidity, temperature, rainfall and local wind variations, over the year. Local anabatic (upslope) and katabatic (downslope) winds on the volcano's flanks could greatly modify exposure. In the wet season ground level winds blow towards the volcano in the opposite direction to the prevailing winds on some days. The wind changes and rainfall in the wet season may therefore be of great importance in addition to concurrent changes in the crater lake. In all these stages the factors influencing buoyancy and dispersal/dilution of the plume need to be considered, as well as reaction rates involved in conversion of gases and aerosols.

PROPOSED STUDY

A multidisciplinary study is proposed to evaluate the health impact of the emissions of Poas by relating the prevalence of airways-related, skin and eye disorders in the affected population with the levels of gases and acid aerosols in the ambient air.

Exposure of the study population to the volcano's plume will be assessed by measuring:

- The flux and composition of gases (SO_2, HCl, H_2S, HF, etc) and acid and other aerosols from Poas crater.
- The ambient air levels of SO_2 and sulphate aerosol in the impacted areas.
- The composition and geographical distribution of acid rain associated with the volcano's plume, as an additional measure of the distribution and toxic load of the plume.
- The meteorological parameters that affect dispersion and diffusion of the plume gases.

The health impact will be evaluated by:

- Epidemiological prospective monitoring of the numbers of patients with airways-related disorders as recorded by hospitals and health clinics in the study and control areas.

The incidence of eye and skin disorders will also be investigated.
A community survey of airways-related disorders in the study and control areas.

Epidemiologic surveys will be correlated with studies of volcanology, air pollution, meteorology and acid rain. The hypothesis to be tested is that the recent increase in the volcano's output of gases and, in particular, acid aerosol is causally related to an increase in the incidence and prevalence of health effects, namely airways-related disorders, eye and skin complaints in the population downwind.

The almost constant direction and strength of the prevailing winds result in the emissions being blown into the valleys running south-west of Poas and repeatedly affecting inhabitants and outdoor workers in this agricultural area as far as 30km away from the volcano. In addition, fine (sub-micrometer) acid aerosols could be blown for greater distances into the heavily populated central valley region. The extent of the respiratory hazard should become clearer as an outcome of this proposed study, but acid rain (minimum pH2) has been regularly collected over the study area since the recent crisis began (Alfario R., personal communication). Acid rain around volcanoes is mainly formed by hydrogen chloride in the plume dissolving in rain (2,11).

The chemical composition of gases and aerosols, including the size distribution and physical properties of the latter, are intimately linked with the volcano's dynamics. This study would therefore be a unique opportunity to combine the interests of investigators from a range of environmental disciplines.

Poas has been the subject of study by several foreign volcanologists, geochemists and geophysicists over the last decade of its activity, but their work has not been on-going or co-ordinated despite the volcano being under constant monitoring by Costa Rican scientists. One exception has been the continuing programme of microgravity studies undertaken by the Open University, U.K., since 1979. We propose that there should be collaboration between scientists of the Open University, the British Geological Survey, and BRGM, France, to monitor the crater lake/gas interface in more detail. These workers have agreed to collaborate with the principal investigators of this proposal which must of necessity be multi-disciplinary. The following areas for inputs from foreign and Costa Rican volcanologists are foreseen:

1. Measuring the composition and fluxes of gases and aerosols at fumaroles and in the main plume (separate application is being made for funding of a COSPEC instrument to measure SO_2 and HCl).

2. Monitoring of overall activity of volcano, e.g. sismity, microgravity and deformation studies.

3. Geochemistry of crater lake and changes in the lake water over time and in relation to the volcanic activity and gas output.

4. Geochemistry of rivers draining the volcano and which are used for drinking water. Water quality may be of particular importance in the light of reports of gastro-intestinal illness and skin irritation in the area, e.g. these problems could be due to elevated fluoride levels that have already been found (10,12) and low pH, respectively.

STUDY POPULATION

About 30,000 people living southwest and south of Poas volcano in the region served by the hospitals of Grecia and San Ramon, out-patients clinics of Sarchi, Naranjo, Grecia and San Ramon as well as eight health posts. The communities in the impacted area lie between Poas volcano and a line through the towns of San Pedro, Grecia, Sarchi, Naranjo and San Juanillo and are located between 10-20km from the volcano.

The control area chosen for having the same rural and other socio-economic characteristics as the study area, but lying outside the volcano's plume, is Juan Vinas, in Canton Jimenez. It is also comparable in terms of rainfall, altitude, crops grown and absence of industry.

STUDY TEAM

The study team in Costa Rica is multidisciplinary and involves several institutions that are contributing the time of their most qualified staff members and their immediate collaborators. Annex 2 presents a list of members of the study team and of other professionals that have offered their assistance for the successful completion of the research.

METHODS

A. Volcanology

Aims

1. Measure composition and flux of gases and acid aerosols emitted from the crater, and monitor these over time.

2. Monitor level of volcanic activity and relate the measures to gas and aerosol outputs.

Method

1. Measure mean SO_2 levels using SO_2 diffusion tubes distributed in several (approximately 15) key locations in study and control areas. (See Health Study).

2. Use one continuous SO_2 reading monitor in a station set up at a key location in the study area to measure SO_2 peak levels as well as mean levels.

3. Measure aerosol levels using a dichotomous aerosol sampler located as for SO_2 direct reading monitor.

4. Measure total and TP-10 suspended particulates using high volume sampler in same station as 2. and 3.

Equipment and Institutions

1. SO_2 diffusion tubes provided and analysed by Warren Spring Laboratory. Responsibility for field samples: UNA and UCR.

2. SO_2 monitor. Responsibility for readings: UNA.

3. Aerosol sampler. Laboratory analysis: UNA.

4. High volume sampler. Responsibility for readings: UNA.

C. <u>Acid rain</u>

Aims

1. Measure pH, chemical composition (e.g. chloride, sulphate, nitrate, ammonium, sodium, magnesium, calcium, aluminium, potassium, together with fluoride, arsenic, mercury, cadmium) and distribution of acid rain in study and control areas.

2. Correlate acid rain collection with observations of the effect of acid rain on vegetation and buildings in the study area. (Information already routinely collected by UNA). These observations will provide indirect estimates of the toxic acid load of the plume and its distribution during the wet season.

Method

1. Rain collection equipment already in place in certain locations and some observations have been made since 1984. Locations need to be extended and analysis should include a wide range of cations and anions by ion chromatography, equipment that already exists in the B.R.G.M. and also UNA (Lab.- de Contaminantes) is used by UNA also.

2. Field botanical surveys. These have been carried out regularly since 1984 by the team of Professor Rosario Alfaro of UNA, also responsible for the present study.

Equipment and Institutions

1. Twelve simple acid rain collectors. Collection of samples: L.C.- UNA.

2. Rain gauges, portable electronic kit, glass fibre filters, plastic bottles for wet deposition and laboratory reagents for chemical analysis during two years. Responsibility for analysis: L.C.-UNA.

D. METEOROLOGY

Aims

To assist in establishing the parameters needed to investigated the process of transport and dispersion of airborne contaminants and recording relative humidity, wind speed a direction, temperature and rainfall in key locations.

Account for possible meteorologic confounders of respiratory symptoms.

Method

1. Install three meteorological stations located in: Trojas, Grecia and Fraijanes, complemented by 10 local wind stations manned by volunteers (Red Cross, public health clinics), etc.

2. Prepare a map of the meteorological parameters and correlate these with the findings of the health studies (M.S. and I.N.N.).

Equipment and Institutions

1. Three automatic meteorological stations, including keyboard display offload, storage module, PC software and interface.

2. Ten Wind-sock stations.

   Responsibility all measurements: National Meteorologic Institute.

Prospective study

Aim

Correlate the incidence of key diseases and symptoms with the characteristics of the volcanic emissions and their dispersion.

Method

This study will include all the hospitals of Grecia, San Ramon, Juan Vinas, Max Perralta, outpatient clinics and health posts in the study area.

The health staff in these institutions will be asked to undertake data collection as part of their duties. Record forms will be used to collate the number of patients attending with respiratory disorders, skin and eye problems.

In patients with respiratory illnesses a short form will be used to record identification details, diagnosis or presenting symptom (e.g. cough) and the result of peak flow testing.

The data will be analysed for time-trends corresponding to changes in volcanic activity.

Equipment and Institutions

Record forms, peak flow monitors, computer.

A statistician from the Ministry of Health will regularly visit the clinics and hospitals to collect the forms and ensure quality control. Responsibility: Ministry of Health and C.C.S.S. Collaborating institution: Cambridge University.

Community Study

Aims

1. To obtain information on the prevalence and incidence of asthma in the exposed population compared to the control population.

2. To relate clinical symptoms of airways-related disorders with volcanic activity and meteorological parameters.

3. To define the susceptible groups, e.g. asthmatics, atopics or certain occupational age groups.

4. To determine the mechanism of development of airways-related disorders associated with volcanic emissions, e.g. determine whether irritant gases and aerosols induce airways hyperactivity or increase the susceptibility of individuals to allergens commonly present in the environment. The emissions may cause more frequent attacks in asthmatics and

provoke a decrement in lung function in normal people (c.f. ozone).

Method

The study would follow the methodology of the European Community Respiratory Health Survey (13).

Obtain a random sample of 1500 males and 1500 females aged 20-44 in each of the exposed and control areas (3000 people in each area) and in addition two subgroups of children 7-14 in the two areas (selected either via schools or via adults selected for the study).

The adults would be invited to the hospitals to undergo the following examinations:

- Completion of respiratory questionnaire
- Peak-flow measurement
- Undergo skin tests for common allergens (e.g. mixed grasses, house dust, cockroach, sugar cane. These are produced by the main Hospital México of Costa Rica). Rica).
- Obtain blood samples of IgE and RAST screen at hospital laboratory
- Undergo histamine challenge with spirometry by Yan's method (14).

Information on the children would be obtained from their parents using a modification of the adult questionnaire and peak-flow measurements will be performed.

Equipment and Institutions

Spirometer, allergen reagents, methacholine nebuliser, laboratory facilities for measuring IgE and RAST testing.

Computer equipment and software for data collection and analysis. Responsibility: Ministry of Health, in collaboration with the Immunology Department of the Mexico Hospital. Three full-time technicians must be hired to work under medical supervision. Technical support from Cambridge University and London University (St Thomas's Hospital responsible for EC survey in Great Britain). It is proposed that the Costa Rican physician-co-ordinator is trained in the survey techniques at a short (one-week) course at St Thomas's Hospital.

EXPECTED BENEFITS OF THE STUDY

The following contributions to science and to knowledge in Costa Rica are expected:

1. Advance our understanding of volcanic disasters in the context of the International Decade for the Reduction of Natural Disasters. The potential hazard of major gas

release in volcanic areas is poorly understood and worldwide there are at least 30 volcanoes with hot crater-lakes; the findings from this study will apply to these areas.

2. Improve understanding of the health effects of air pollution in general by studying an important natural model of human exposure to acidic gases and aerosols.

3. Advance the understanding of acid rain phenomena and their impact on health in general and in Costa Rica in particular.

4. Improve understanding of micro- and meso-scale climate determinants of the transport, dispersion and chemical transformation of volcanic plumes in general and in particular in the Central Valley of Costa Rica.

5. Contribute to the general understanding of the causative mechanisms of asthma, presently studied by a large multicentric European study with which comparability will be sought. At the same time epidemiological knowledge of asthma in Costa Rica will be widened.

7. Define the size of the health problem caused by the emissions in Costa Rica:

    a. Severity of the respiratory problems

    b. Geographical extent, e.g. only certain clinics or hospitals may show an increase in health problems.

8. Improve understanding of the causal factors giving rise to the health problems, e.g. role of gases and aerosols during the different phases of volcanic activity.

As the two institutions (Ministry of Health and National Emergency Commission) responsible for implementing measures to protect the Costa Rican population from the negative effect of the volcano are represented in the study team, concrete applications are also expected. The study will identify what measures of mitigation are appropriate and thus contribute to the International Decade for Disaster Reduction. The following are among the many concrete examples:

1. The research should identify appropriate techniques for monitoring hazards due to volcanic activity. An important finding in the planning of this study was the inability to undertake a retrospective epidemiological study of acute cases of respiratory diseases attending hospitals and clinics in the area impacted by Poas emissions, and a methodology that has been usefully applied in air pollution incidents (15). This type of information may need to be rapidly obtained in disaster situations in order to evaluate the size of a hazard, e.g. in a future gas crisis at Poas or from volcanic activity at Irazu. In 1963-65 repeated

ashfalls from eruptions of Irazu fell on San Jose and the Central Valley area. In any future eruption it will be essential to monitor cases of acute respiratory and other diseases during the crisis periods and appropriate epidemiological systems for doing this need to be established as an integral part of disaster planning for Costa Rica.

The ability of the study team to respond flexibly to a crisis at Poas or other nearby volcanoes such as Irazu needs to be incorporated into the study plan.

2. If long term exposure favours the development of chronic diseases, such as asthma, governments of Central American countries may decide to adopt policies that discourage human settlements near hot crater-lake degassing volcanoes. For example, they may buy land to create national parks, while taking measures to protect the health of visitors and rangers (the study would help clarify what measures may be necessary).

3. If emissions are toxic for only short periods of time that can be either predicted (for example when the crater lake dries up at the end of the dry season or when winds are blowing in certain directions) or detected through appropriate monitoring, it may be appropriate to evacuate settlements or individuals with specific respiratory disorders during these periods, or advise them on staying indoors.

4. In the case of Poas it would be relatively easy to alter the quantity of water in the crater artificially as a way of controlling the gas emissions. The study will make it possible to decide on the usefulness of either increasing or decreasing the volume of water during particular seasons (such variations occur naturally due to the pattern of rainfall through the year, but their impact on emissions is unknown). An increase in the water level could be achieved simply by running in water from Botas, the crater lake situated above Poas crater.

5. Specific health education messages may emerge from an understanding of the impact of volcanic gas. For example, volcanic gases may potentiate the effects of respiratory allergens or the irritation caused by smoking.

6. Advance expertise in volcano monitoring in Costa Rica by developing skills in gas sampling and analysis techniques.

7. Improve the response of the health services in Costa Rica to environmental hazard and provide advice on the medical management of patients with respiratory disorders, e.g. identify risk factors such as pre-existing asthma.

8. Although the study presented here focuses on human health, the results of monitoring of gas emissions and distribution

will assist specialists in the fields of agriculture, forestry and animal husbandry in making decisions on land utilisation in areas close to the crater.

ANNEXES

1. Costs associated with the proposed research.

2. Members of the study team in Costa Rica and of other professionals that have offered their assistance.

3. References.

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