

Geothermal Hazards. Mercury Emission

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■ Enthusiasm for intensified geothermal exploration may induce many participants to overlook a long-term potential toxicity hazard possibly associated with the tapping of magmatic steam. The association of high atmospheric Hg levels with geothermal activity has been established both in Hawaii and Iceland, and it has been shown that mercury can be introduced into the atmosphere from fumaroles, hot springs, and magmatic sources. These arguments, extended to thallium, selenium, and other hazardous elements, underscore the need for environmental monitoring in conjunction with the delivery of magmatic steam to the surface.

Long-standing regional interests in the development of geothermal power have received fresh impetus from present-day anxieties about world energy resources. Although the regions with geothermal potential are relatively restricted geologically, they include many widely scattered locations: Central America, Hawaii, Iceland, Italy, Japan, New Zealand, and the USSR.

Pressures for intensified geothermal exploration may induce many enthusiasts to overlook a long-term potential hazard associated with the tapping of magmatic heat sources. We refer to the release into the atmosphere of substances far more toxic and persistent than the usual oxides and hydrides of carbon and sulfur. As Bullard (1) notes, the production of geothermally based electricity depends upon the trapping of natural steam from primary (magmatic), secondary (groundwater), or mixed sources. The first of these is generally more important in practice. The critical temperature of water is 374°C, well below any magma, hence primary steam surfaces at a temperature greater than the boiling or sublimation points of Hg⁰, HgCl₂, As₂O₃, SeO₂, SeC₂, OsO₂, and many other toxic substances known to be present in magmas or magmatic extrusives (1-12). Exposure of the surface environment (and personnel) to magmatic effluents carried with the steam could take place during drilling or venting or subsequently when the spent steam collects as ponds of hot water condensate. It has been shown that mercury can be introduced into the atmosphere from fumaroles, hot springs, and magmatic sources; fumaroles as well can result in the weathering of igneous rock (2, 13-15). The association of high atmospheric Hg levels with geothermal activity has been established both in Hawaii and Iceland (Table I). Similar figures were obtained from samples taken in Iceland, June-July 1972 (14), and from Hawaiian samples taken from April 1971 to April 1973. Replicate samples were taken using portable battery-operated pumps drawing 0.2-0.4 m³ of air through nitric acid traps. Collections were carried out under a variety of weather conditions but with little or no perceptible air (wind)

movement. Magmatic and fumarolic samples were taken within 0.5 km from the source at an elevation of about 1.5 meters. Air samples from nonthermal areas in both locations differ but little from one another and are approximately an order of magnitude lower than those taken at active sites. Most significantly, the lowest values in Iceland and Hawaii far exceed even the general figure for air over nonmineralized sites (16). In Hawaii the nonthermal samples were taken on Oahu and Kauai and at least 350 km over water from the center of thermal activity at Kilauea, Island of Hawaii.

In the Sulfur Banks area, fallout measurements have been shown to be a function of atmospheric mercury levels (15); it can be calculated that quantities on the order of several grams per hectare can be deposited in as little as 1 hr. With only 5 ppb of mercury in the top cm of soil, the substantial quantities of mercury deposited must be further distributed. Removal by leaching has not been investigated, but accumulation in living matter accounts for a part of the mercury input.

This has been made evident by over 300 determinations of plant-soil or plant-water concentration ratios from thermal and nonthermal sites (17). It appears that although the concentration factor for most plants is 10, a significant fraction accumulates at least 20-fold more Hg than is present in the soil. In marine and aquatic plants examined, the accumulation of mercury is even more extreme, with ratios of 100 to more than 1000.

Other field studies in progress have shown that mercury is commonly concentrated 10- to 100-fold in soil fungi and

Table I. Comparative Aerometry of Mercury at Icelandic and Hawaiian Thermal and Volcanic Sites

| Location | Areas sampled | No. samples | Mercury level, ^a μg × m ⁻³ | |
|-------------------------|---------------|-------------|--|-------------|
| | | | Range | Mean ± S.E. |
| Iceland | | | | |
| Fumarolic | 5 | 16 | 1.3-37.0 | 10.0 ± 5.2 |
| Magmatic | 1 | 3 | 4.8-7.6 | 6.1 ± 0.6 |
| Nonthermal | 2 | 3 | 0.62-1.0 | 0.8 ± 0.2 |
| Hawaii | | | | |
| Fumarolic | 1 | 21 | 1.0-40.7 | 17.6 ± 6.1 |
| Magmatic | 2 | 13 | 0.7-40.5 | 17.1 ± 6.8 |
| Nonthermal | 3 | 10 | 0.04-0.3 | 1.1 ± 0.5 |
| Cincinnati ^b | — | — | 0.03-0.21 | <0.21 |
| New York | — | — | ≤0.014 | <0.014 |
| Palo Alto | — | — | ≤0.01 | <0.01 |
| E. Pacific | — | — | ≤0.0007 | <0.0007 |
| General | — | — | 0.003-0.030 | <0.03 |

^a Samples were collected in nitric acid traps using battery-operated pumps. Analyses were carried out in duplicate or triplicate by the flameless atomic absorption procedure (15). ^b Cincinnati, New York, and Palo Alto after Schroeder (18); Pacific and general figures after McCarthy (16).

in invertebrate animals including corals, echinoids, annelids, and millipedes. Soil samples collected in Japan, Nepal, and Taiwan yield 200-1000 ppb of mercury, and the feathers of seabirds may exceed 3000 ppb.

Environmental contamination by geothermal mercury has both long- and short-term consequences. The gradual increase of mercury levels in the biosphere is inevitable as lavas and other igneous extrusives break down, releasing their contents into existing, or forming, soils and sediments. Some of the mercury from primary sources has without doubt been cycled many times through sedimentary and metamorphic rocks as well. Thus we account for high mercury levels in vegetation now far removed from current centers of thermal activity.

Short-term effects depend upon atmospheric transport and deposition of gaseous mercury now being released at active sites. In this context, the most immediate biological consequences include the human hazard. Schroeder (18) considers prolonged exposure to atmospheric levels in excess of $0.1 \mu\text{g} \times \text{m}^{-3}$ to be harmful. We have shown here that levels well in excess of $0.1 \mu\text{g} \times \text{m}^{-3}$ exist even at distances of 350 km or more from the active site (in Hawaii). In proximity to thermal areas, where levels as high as $37\text{-}40 \mu\text{g} \times \text{m}^{-3}$ may be found, the human (and general mammalian) hazard is commensurately greater.

Whatever may be the source of mercury, the capacity for bioconcentration among both terrestrial and aquatic organisms must enhance the penetration and distribution of mercury with and among ecosystems and food chains. In the marine milieu, the role of submarine vulcanism as a source of mercury in sea life has not been investigated.

Although no direct link has been established previously between trace element distribution and gaseous emissions at thermal sites, the situation described for mercury should be no less applicable to many more elements than those named above. We urge that suitable health and ecological monitoring programs be included in any plans for geothermal exploration.

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SIR: Since the publication of "Piezoelectric Sensor for Mercury in Air" [Eugene P. Scheide and John K. Taylor, *Environ. Sci. Technol.*, 8, (13), 1097 (1974)], previous work describing a similar technique has come to our attention ["An Evaluation of the Quartz Crystal Microbalance as a Mercury Vapor Sensor for Soil Gases," Q. Bristow, *J. Geochem. Explor.*, 1, 55 (1972)]. We regret not acknowledging this work in our paper and the oversight of not picking it up in a literature survey.

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