A GEOTHERMAL PRIMER; SOME ISSUES AND SOME ANSWERS

During the last several months a number of concerns have been expressed regarding adverse environmental and health impacts of anticipated geothermal development in Hawaii. Some of the concerns expressed have merit and raise issues that should be studied by permitting agencies reviewing applications for proposed geothermal development. However, some of the issues raised, in my opinion, are not based on factual evidence and do not reflect a realistic evaluation of available information. Having spent the last seven years working with the chemistry of the fluids from the HGP-A well and almost ten years studying the gas emissions of Kilauea volcano, I would like to present some of the data that has been accumulated and attempt to place some of the geothermal issues into a perspective where they can be judged as to their merit and their potential for future concern.

One of the most frequently raised issues is that of potential air pollution from geothermal development and the environmental and health impacts resulting from geothermal emissions. The elements or compounds that are alleged to be emitted to the atmosphere by a geothermal plant are quite numerous: mercury, lead, arsenic, radon and radon decay products (radon daughters), hydrogen sulfide and sulfur dioxide. Analyses and calculations for the emission levels of each of these have been conducted numerous times at the HGP-A facility. I would like to present a detailed discussion of what we have learned about each of these substances and how they relate to the geothermal debate.
Mercury, lead, and arsenic are all termed "heavy metals" and have a substantial toxicity at low to moderate concentrations. These metals cycle through the environment and are taken up by plants and animals much like any other element or compound; they may even play a role at some levels as a nutrient or essential element much like zinc or selenium, two other "heavy metals." Their threshold of toxicity is, however, very low compared to other metals such as sodium, calcium, or iron and, because of this, there is a very real concern about any process that generates substantial quantities of these elements.

During early testing of the HGP-A well, analyses were conducted for these elements and it was reported that small quantities of mercury were present in the geothermal steam. The levels reported were on the order of a few parts per billion (ppb). It is of note that analysing for substances at these levels is very difficult; for comparative purposes, one part per million (ppm) is the equivalent of one ounce of sugar in one truck load (31 tons) of sand and one part per billion (ppb) is one ounce of sugar in one thousand truck loads of sand. During more recent testing at HGP-A we have refined our sampling and analysis procedures, and using these procedures we have analysed repeatedly for mercury, lead, and arsenic in the geothermal steam. The results of these analyses have indicated that none of these metals are present in the steam at detectable concentrations. We cannot say unequivocally that the earlier analyses were in error; however, we can say that detectable amounts of these metals are not now being emitted and that it is highly probable, on the basis of the more recent data, that they never were.

One of the major concerns related to the supposed emission of these metals was contamination of drinking water catchment systems. We have been conducting analyses of rainfall catchment systems around the HGP-A power plant for approximately two years; to date we have never found elevated levels of any heavy metals that could
be attributed to steam discharges from the geothermal wells in Lower Puna. On the basis of the data that we have collected at HGP-A and on private rainfall catchment systems over the last two years, I do not believe that emissions of heavy metals from a geothermal plant in Hawaii will pose a significant, or even detectable, environmental hazard. Nonetheless, in the interest of prudence and caution, I would agree that monitoring of operational geothermal wells should be conducted on a periodic basis to ensure that, if they are found, proper abatement measures can be taken.

Radon is a member of what is called a radioactive decay chain that begins with uranium and thorium. The latter two elements are naturally occurring radioactive substances that are present in the earth's crust (soil, rocks, magma, etc.) at detectable quantities. These elements slowly decay and, with each radioactive decay step, change into another element until a non radioactive (stable) element is formed. Because uranium and thorium are present in rocks, soils, and magma and, because radon is a member of the decay chains of these elements, radon is present in groundwater and rainwater, in the soil, and in the air we breathe. Is radon hazardous or dangerous? The answer to that question is much the same as that regarding "heavy metals." If radon is allowed to accumulate to high concentrations, then it can be very hazardous. However, as long as the concentration remains low it does not present a detectable hazard.

The radon concentrations in the geothermal fluids at HGP-A have been analysed; the levels detected were about 8% to 10% of those found at the Geysers geothermal field and hence were not considered to pose a hazard to those working at the site or to the general public. Nonetheless, as an extra measure of safety, the gases containing the highest concentrations of radon in the power plant are being fed into the cooling tower where they are diluted by a very large volume of air. Using this procedure, the maximum concentration of radon in any plant effluent is approximately 90 pico curies per cubic meter (p Ci/m³) of air. For comparison, measured
outdoor (ambient air) concentrations or radon have been found to range from 50-1000 pCi/m³ in Illinois, from 20-500 pCi/m³ in New York, and from 170-1040 pCi/m³ in Ohio. Indoor concentrations of radon, where the air is stagnant and there is slower dilution of the radon emitted by building materials, have been measured in the range of 130-4800 pCi/m³ and in some cases as high as 10,000 pCi/m³. Measurement of radon in soil gases in Hawaii indicate concentrations in the range of 100-200 pCi/m³. Hence, the radiation exposure received by someone standing at the radon emission point for a geothermal plant would be about the same as that received at home in bed. Even though the exposure levels are low, there is still considerable debate as to the effects of low levels of radiation; the general consensus among experts in the field, however, is that exposure to radiation levels within the range of natural background does not pose a detectable hazard to human health.

An issue very closely related to radon exposure is that of accumulation of radon decay or daughter products within and around a geothermal facility. It is a relatively simple procedure, using standard nuclear chemistry equations, to calculate what the deposition rate of these elements would be. In order to do these calculations one must assume a time period for deposition, an average wind speed and direction and the deposition rate of decay product (i.e. the rate at which it falls out of the air after the decay from radon gas occurs). Even if very conservative assumptions are made (i.e. the worst case conceivable) of one hundred years of deposition with an average wind speed of one mile per hour over one quarter of the land surface around a three hundred megawatt plant, and instantaneous deposition of the decay products, the accumulated radon daughter products would increase the already existing levels of these elements in the soil by less than 1%. If more reasonable assumptions are made of 5-8 mile per hour wind speed, deposition over one half the area around a power plant and a 2 day average residence time of the decay products in the atmosphere (as has been measured), the resulting addition of the radon daughters is less than one one-thousandth of one percent (0.001%) of the existing levels. This deposition rate, in my opinion, does not pose a significant,
or even detectable hazard to the environment or to human health.

Hydrogen sulfide is most frequently characterized by its rotten egg odor. Hydrogen sulfide, like the heavy metals, is very toxic at relatively low concentrations in the air; at about 800-1200 parts per million in air, it can cause death after only short exposure and at lower concentrations it can cause a number of irritative effects. Unlike "heavy metals" though, there is no evidence that hydrogen sulfide is a "cumulative" poison; this is to say that long exposure to low levels (on the order of one part per million or less) is unlikely to produce long-term or gradually more toxic effects. Because of the toxic and irritative effects of hydrogen sulfide at concentrations in excess of 1 ppm, the Occupational Safety and Health Administration (OSHA) has set a maximum worker exposure level of 10 parts per million for an eight hour day and forty hour week. As noted above, hydrogen sulfide does have a very strong odor even at very low levels and even though there is considerable disagreement in the scientific literature, odor detection thresholds ranging from as low as one half part per billion to more than fifty parts per billion have been reported and thus H_{2}S can be detected by its odor at levels well below those considered to be toxic.

Contrary to some comments made about hydrogen sulfide, it's not largely a man-made product of industry. Hydrogen sulfide is naturally produced from numerous sources; biological decay or digestion by several forms of bacteria is the single largest natural source of atmospheric hydrogen sulfide on earth. The second largest source of H_{2}S is volcanic activity and, together, biological and volcanic sources produce an estimated 60 million tons per year of H_{2}S in the northern hemisphere alone. Natural background levels of H_{2}S along the lower East Rift Zone of Kilauea have been measured over the last year at 3-5 parts per billion; background levels in other continental areas have been found to be of the same order of magnitude as those found in Hawaii. Thus, exposure to low levels of H_{2}S is a virtually continuous condition for plants, animals, and humans.
Hydrogen sulfide is present in the geothermal fluids produced by the geothermal wells in Hawaii at a relatively high concentration (900-1000 parts per million in the steam phase). This hydrogen sulfide is the result of high temperature reactions of water with the geothermal reservoir rock. If the hydrogen sulfide produced by the HGP-A geothermal well was released directly to the atmosphere unabated, a considerable nuisance could be created. For this reason, a hydrogen sulfide abatement program has been underway at HGP-A facility since 1979. This program has required the installation of several hundred thousand dollars worth of equipment and costs more than twenty thousand dollars a month to operate. What is more important, however, is that it works. Less than one percent of the hydrogen sulfide that enters the HGP-A power plant is allowed to escape. This was, admittedly, not the case when the power plant was initially started up in June 1981; only about eighty to ninety percent of the $H_2S$ was abated during the start-up operations and the odor of $H_2S$ was quite apparent around the power plant and occasionally in the adjacent community. However, it should be remembered that this was the first geothermal plant installed on this reservoir. Techniques and processes that had routinely been used in other geothermal fields were suddenly found to be unworkable here. It is perhaps an unfortunate characteristic of geothermal wells that they cannot be turned on and off repeatedly like a water faucet and that geothermal power plants cannot be tested without a source of steam. Because of these circumstances, those of us associated with the HGP-A plant were forced to modify and perfect and invent the processes we needed to make the plant work while the well was still operating. In spite of the difficulties encountered, we were able to correct the major problems in a very short period of operating time and we are continuing to make modifications and improvements even up to the present time. Now that we have been through this experience and have developed the techniques required for hydrogen sulfide abatement under virtually all operating conditions, future geothermal plants built in Hawaii can make use of our experience in their design.

In-so-far as hydrogen sulfide emissions by future geothermal development is concerned, there is currently under review by the Department of Health an ambient
hydrogen sulfide standard for geothermal emissions. As this standard is presently written, it will be necessary for an operator of a geothermal facility to demonstrate through accepted air quality modelling that the ambient air concentration of hydrogen sulfide from all man-made sources including that from the proposed facility will not exceed the natural background level by more than 25 parts per billion averaged over a one hour period. The operator of a power plant must demonstrate that this level will not be exceeded even for the worst possible (i.e. least favorable) dispersion or weather conditions anticipated over a full year. Only if he is able to demonstrate that fact to the satisfaction of the Director of the Department of Health using EPA accepted procedures, will he be able to construct or operate a geothermal facility. Ambient hydrogen sulfide levels during the remainder of the year will have to be less than this level and would, during the greatest majority of the time, be indistinguishable from existing background as is currently the case at HGP-A.

Another allegation that has been raised that is closely tied to hydrogen sulfide emissions is that geothermal emissions will create acid rain. This, in my opinion, is one of the most cynical and malicious charges made against geothermal energy in light of the fact that geothermal development could have exactly the opposite effect. The sources and impacts of acid rain are very complex issues that have received a lot of attention on the mainland and in Europe. Although the "finer points" of acid rain generation are still being hotly debated, the general understanding is that sulfur dioxide and nitrogen oxides generated by the combustion of coal, oil, or gasoline can form sulfuric acid and nitric acid in the atmosphere. These acids precipitate out of the atmosphere with particulate (dust) or in rainfall. The acid that is deposited can have extremely detrimental effects on plant, animal, and aquatic life.

The question that should be raised here is, "How does acid rain relate to geothermal development where neither coal nor oil are burned?" The relationship, though tenuous at best, is that hydrogen sulfide can also convert to sulfuric acid
in the atmosphere. However, an examination of the numbers indicates just how much of an acid rain hazard there is. In order for a geothermal plant to meet EPA guidelines for $\text{H}_2\text{S}$ emissions, the release rate of hydrogen sulfide must be less than 200 grams per megawatt of electricity produced per hour. This would amount to about ten kilograms (about 22 lbs) per hour for a fifty megawatt plant. However, if a plant is to meet the proposed Department of Health ambient standards, an emission rate of no more than approximately 350 grams total per hour is calculated using a standard dispersion modelling equation. This means then that a 50 megawatt geothermal plant, if it is to meet the proposed Department of Health standards, will have to be able to reduce its emissions to approximately one half to one pound per hour.

How does this figure compare with other sources of sulfur on the island? Halemaumau is estimated to emit from 100 to 150 tons per day of sulfur dioxide (along with substantial volumes of sulfuric acid vapor directly). The recent Kilauea East Rift Zone eruption that began early this year was estimated to have emitted one thousand tons per day of sulfur dioxide during its most active period; the rift zone around the eruption site is still emitting considerable quantities of sulfur dioxide and sulfuric acid. But these are all natural sources and, regardless of the damage they may do, there is little that can be done about them. However, there are also man-made sources on the island. One of these is the electrical generating facility in Hilo which produces approximately forty megawatts of power; it also produces about 3 tons per day of sulfur dioxide and an estimated 0.4 tons per day of nitrogen oxides. So, how do we compare all of the numbers on an equal basis? For purposes of simplicity let's say that all of the various sulfur compounds convert instantly to sulfuric acid (even though it takes considerably longer for $\text{H}_2\text{S}$ to go to sulfuric acid than does sulfur dioxide) and that half of the sulfuric acid deposits on the ground before it can escape from the island. To be even more conservative let's assume that a very sharp operator has talked the Department of Health into allowing him to emit five times the amount of $\text{H}_2\text{S}$ that was calculated.
to meet the presently proposed standard. Using these numbers then, the geothermal plant would deposit about 135 pounds per day, the East Rift Zone would have deposited about 1,5000,000 lbs per day during the eruption and possibly 75,000 lbs per day now, and the 40 megawatt oil fired power plant in Hilo would deposit about 4,600 lbs per day. A little elementary arithmetic using these numbers shows that if the oil fired plant is shut down when the first forty megawatts of geothermal electricity becomes available another one thousand three hundred megawatts of geothermal power would have to be generated before we would have the same sulfur emissions as are currently occurring from the existing plant and still not produce three percent of Kilauea's sulfur emissions during the non-eruptive periods. The forecast for acid rain from geothermal development is about as accurate as one for snow in downtown Hilo.

The above discussions should also amply demonstrate the absurdity of the allegation that geothermal development will produce the same air quality conditions as those occurring during the current eruption. This allegation does demonstrate, however, the lengths that those opposed to geothermal development will go in an effort to smear the geothermal industry and to mislead the people of Hawaii.

Another set of issues that have been raised relate to the concern about contamination of potable groundwaters with geothermal effluents. This is a valid concern and has received considerable attention from all State agencies associated with groundwater quality and with geothermal development. At the present time, the HGP-A generator facility is disposing of its spent geothermal liquid effluent by surface percolation. This procedure was allowed only because the groundwaters around HGP-A well were known to be already contaminated by the natural intrusion of saline geothermal fluids into shallow groundwater supplies in Lower Puna. The salinity of some of the groundwaters around HGP-A were even saltier than the geothermal fluids and are of little use for human consumption or irrigation. Even though there was little expectation that these groundwaters would be detectably
contaminated by the relatively small volumes of fluid disposed of at HGP-A, several shallow groundwater wells in the area have been monitored over the last two years. After nearly eighteen months of operation at HGP-A, there has been no detectable impact on the water quality in any of the wells monitored.

The fact that we have not observed groundwater contamination near HGP-A should not be taken to indicate that larger geothermal facilities will be allowed to dispose of their liquid effluents by surface percolation. Prudence dictates as will the Department of Health, that disposal of any waste waters from geothermal development will have to be by an approved waste water reinjection system. The liquid effluents, in my opinion, should be reinjected to a depth that will not contaminate fresh water supplies and into an aquifer of similar water quality. Such regulations can be designed to preclude any possibility of degrading fresh water or drinking water supplies by the disposal of geothermal effluents from electrical or direct use applications of Hawaii's geothermal resources.

There have been numerous other issues and allegations raised about geothermal development; those that have merit have been examined and appropriate action has been taken or plans made to mitigate or eliminate the adverse impacts of concern. Those that do not have merit should be laid to rest once and for all so that real concerns and real issues can be addressed properly and the people of Hawaii can make an informed choice as to their preference for alternative energy development.

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