Letters

Geothermal Power Plants: Environmental Impact

Robert C. Axtmann, in his article "Environmental impact of a geothermal power plant" (7 March, p. 795), seems to have overlooked the possibility (indeed, probability) of the release of radioisotopes to the environment. In view of the ever-present criticism of nuclear power plants on this count, it is worthwhile pointing out that "alternate energy" sources can contribute to increased environmental radioactivity.

Although no measurements are indicated in Axtmann's discussion of the Wairakei, New Zealand, geothermal plant, groundwater including geothermal water typically contains dissolved radium and radon. For example, groundwaters in Maine were reported (*1*) to have concentrations of ^{222}Rn plus its daughters through ^{214}Po ranging to $\sim 10^6$ picocuries per liter, with an average concentration of $<88,000$ pCi/liter for 128 drilled wells. In a study (*2*) of ^{222}Rn in water in Britain, it was concluded that wells, springs, and boreholes in areas where the fundamental geologic formation was granite almost never exhibited ^{222}Rn concentrations less than 1000 pCi/liter. Hot springs in Badgastein, Austria, have ^{222}Rn concentrations which result in $\sim 15,000$ pCi/liter in the thermal bathwater (*3*). Indeed, measurements of ^{222}Rn in the Wairakei geothermal region were reported (*4*) in 1959. Values associated with discharges from pools and fumaroles ranged from 18,000 to 320,000 pCi/liter of gas discharge (mostly carbon dioxide) and from 40,000 to 770,000 pCi/liter of liquid condensate.

Thus there is no reason to assume that ^{222}Rn is not present in the geothermal water and steam employed in the Wairakei power plant. If one assumes for the sake of discussion a ^{222}Rn content of 100,000 pCi per kilogram of discharge, then the 0.8×10^6 kg/hour of water vapor release implies a release of 80 mCi/hour of ^{222}Rn to the atmosphere. Furthermore, the aqueous discharge of about 4.7×10^6 kg/hour implies a ^{222}Rn discharge of 470 mCi/hour from the plant. A substantial portion of this ^{222}Rn will subsequently enter the atmosphere. Any nongaseous radionuclides present in the discharge (such as ^{226}Ra) will enter the river. In addition to environmental releases, radon daughters may build up on interior surfaces of power plant equipment in a situation analogous to that recently discovered in natural gas processing (*5*). This potential buildup could result in occupational exposure to radiation and radioactivity. Radioactivity in geothermal power production discharges should be measured and human exposure pathways evaluated.

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References

1. B. M. Smith, W. N. Grune, F. B. Higgins, Jr., J. G. Terrill, Jr., *J. Am. Water Works Assoc.* **53**, 75 (1961).
2. A. W. Kenny, R. N. Crooks, J. R. W. Kerr, *J. Inst. Water Eng.* **20**, 123 (1966).
3. J. Pohl-Rüling and F. Scheminzky, in *The Natural Radiation Environment II*, J. A. S. Adams, W. M. Lowder, T. F. Gesell, Eds. (Report CONF-720805, Energy Research and Development Administration, Oak Ridge, Tenn., 1975), pp. 393–419.
4. R. E. Belin, *Geochim. Cosmochim. Acta* **16**, 181 (1959).
5. T. F. Gesell, *Health Phys.*, in press.

Axtmann fails to mention that radionuclides are to be found in both the air and water releases of any geothermal installation. At the present time there is little data available with which to accurately determine the environmental significance of these releases. Kruger (*1*) has shown that the concentration of radon in air over the Geysers power plant in California is less than the 0.3 picocurie per liter found in air over typical continental landmasses. It remains to be seen if this measurement can be extrapolated to other installations. However, the Department of the Interior has suggested monitoring of radon at all geothermal sites leased from the government (*1, 2*).

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References

1. P. Kruger, paper prepared for the "Workshop on the environmental aspects of geothermal resources development," Pacific Grove, Calif., November 1974.
2. *Final Environmental Statement for Geothermal Leasing Program* (Department of the Interior, Washington, D.C., 1973), p. III-59.

Axtmann's analysis of the environmental impact of the Wairakei power plant is a conscientious and honest article, but many of the main conclusions are probably misleading. He points out the waste of hot water which, in very large quantities, is poured into the Waikato River and states twice that there is no experience of reinjection of hot water in a liquid-dominated field. This is not correct; the United Nations has tested a recharge system for 8 months in the Ahuachapan field in El Salvador (*1*), and reinjection is being carried out regularly in the Otake field in Japan (*2*). There is no known case where the recharge of hot water in a hot water field has failed. Moreover, the New Zealand authorities have stated that they "will not be using the Wairakei method of waste water disposals in other fields to be developed in New Zealand" (*3*).

Axtmann, generalizing from his observations of the Wairakei field, concludes that the efficiency of geothermal power plants should be improved because, if geothermal power is widely used, it could make too high a contribution to the heat balance of the globe. From the Wairakei experience, such a conclusion appears reasonable, but from a world geothermal overview, the situation is quite different. Much more geothermal energy is used in nonelectric applications, such as house-heating, crop-drying, industrial processing, and so forth, than for the generation of electricity, and this multipurpose utilization is increasing. It is only in electricity generation that geothermal energy is used less efficiently than the electricity in fuel stations. Where geothermal hot water and steam are used directly for nonelectric applications, they have a 40 to 50 percent higher energy efficiency than hot water and steam produced in a boiler using fuel. It is likely, therefore, that the total global use of geothermal resources is today more energy efficient than the present use of steam or hot water produced in boilers (*4*).

As do many others, Axtmann regards the release of carbon dioxide to the atmosphere as a possible danger. However, agriculture researchers see in the availability of CO_2 the opportunity to increase production of plants and fibers. It has been suggested (*5*) that the CO_2 content of crop-growing atmospheres be increased from the present level of approximately 330 parts per million to as much as 1000 parts per million. It should not be assumed that any release of CO_2 is a negative factor until proper research has settled the issue.

Two minor points in Axtmann's article should also be corrected. He states that aquifer pressures and deep water temperatures have decreased in the Wairakei field, but in an official New Zealand government statement (*3*), we read: "It is important to note that temperatures below saturation level have not fallen." Axtmann also implies that a geothermal plant needs an "adequate source of cooling water." However, a geothermal power station can use its own water production for cooling, as is done in the Geysers field in California.

Most important, Axtmann appears not to realize that if a geothermal field is developed for electricity generation only, as in the case of Wairakei, its lack of efficiency represents a failure of government policy; such one-dimensional development is not a necessary feature of the use of geothermal energy. Private interests in New Zealand have developed hot water fields for use in timber processing, air-conditioning, house-heating, and so forth. Axtmann's study would have been tremendously improved if he had compared the narrow, one-sided, and, I believe, least economic kind of development typified by the Wairakei field with the multipurpose development of other areas in New Zealand.

Axtmann does not note that geothermal energy is perhaps the only natural resource which pollutes the environment if left undeveloped (Yellowstone releases more than 100 tons of arsenic per year). He mentions that the development of the Wairakei field has reduced or stopped a number of hot springs which released both heat and pollutants. He should, therefore, have measured the environmental effects of these surface emanations and calculated the net or additional pollution created by the Wairakei field—with all its shortcomings in development.

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References

1. J. Barnea, *Sci. Am.* **226**, 70 (January 1972).
2. Japan Geothermal Energy Association, *Geothermics* **3**, 122 (1974).
3. N. C. McLeod and R. S. Bolton, in *Geothermal Energy* (hearings before the U.S. House of Representatives, Committee on Science and Astronautics, Subcommittee on Energy) (Government Printing Office, Washington, D.C., 1973), p. 211.
4. J. Barnea, "Economics of multi-purpose use of geothermal resources," paper presented at the International Conference on Geothermal Energy for Industrial, Agricultural, and Commercial-Residential Use, Klamath Falls, Ore., October 1974.
5. S. H. Wittwer, *BioScience* **24**, 216 (1974).

My failure to consider radioactive releases was a serious omission. I forwarded the recommendations of Gesell and Adams to my New Zealand colleagues only to learn that they had begun such a program earlier this year (*1*). As of now however, Belin's results (*2*) appear to be the only ones available that might have even marginal relevance to the Wairakei effluents.

In the meantime Stoker and Kruger report (*3*) that they have measured radon concentrations at several geothermal reservoirs—presumably in the United States. They conclude that "the environmental impact of radon release to the atmosphere appears to be small and indistinguishable from the release of radon by natural emanation from the surrounding land mass."

The Wairakei situation might be very different from that described by Stoker and Kruger if (i) the estimate by Gesell and Adams of the ^{222}Rn content of the geofluid turns out to be accurate and (ii) any significant fraction of the corresponding source (about 5000 Ci/year) becomes airborne. A rough computation, based on methods for estimating ^{222}Rn doses from piles of uranium mill tailings (*4*), indicates that the downwind radon dose rate at 1 kilometer from the Wairakei plant could be greater than 100 mrem/year. Radon transport through the environment and ^{222}Rn dosimetry are extremely complex and difficult subjects (*4*), however, and a few measurements would be worth scores of rough computations.

Barnea makes an eloquent case for the multipurpose utilization of geothermal resources. Although my article was on a different subject (he seems to argue that I chose the *wrong* subject), I certainly agree that nonelectrical uses are important.

I cannot agree, from Barnea's evidence, that "many of the main conclusions are probably misleading." The major conclusions are listed in the summary of the article; Barnea makes no comment on any of them. He does attack a number of minor points with a dazzling display of fallacious reasoning. My favorite is a textbook example of ignoratio elenchi (*5*): he suggests that I should not be concerned with rising atmospheric CO_2 levels because they could have a salubrious effect on agriculture. His argument implies that there would be a trade-off between melting the polar ice caps and producing a better cotton crop. There would not.

Barnea then "corrects" two minor points with straightforward non sequiturs and plunges on to a superb secundum quid. He reveals that my "most important" transgression was not scoring my New Zealand hosts for their "failure of government policy." At this point I could plead gentlemanly diffidence, but there are important historical, technical, and economic facts that Barnea ignores when he insists that the Wairakei plant should be producing electrical power, industrial process heat, and domestic heating and cooling.

The Wairakei plant was originally conceived to provide electricity for New Zealand and heavy water for the United Kingdom. Late in the design stage the United Kingdom's thirst for heavy water disappeared (or was quenched), the British government withdrew from the project, and the plant was completed as a central station power source (*6*).

It is important to note that both the electrical and heavy water sections would have employed live steam and *not* the waste water discharge which is produced at approximately 100°C in the flashing process. As I mentioned in my article and have discussed more extensively elsewhere (*7*), the difficulty is that the discharge is supersaturated in amorphous silica. When the latter precipitates on heat exchanger surfaces, it fouls them and prevents utilization of the waste heat. The New Zealand Department of Scientific and Industrial Research (DSIR) has worked vigorously on this problem for a number of years. In May 1975 two DSIR scientists announced a possible solution: treating the supernatant fluid to precipitate the silica before it reaches a heat exchanger (*8*). In short, it may now be possible to use some of the energy whose waste Barnea (and I) so deplore.

If, that is, there is a market for the energy. The Wairakei reservoir is in a sparsely populated region, so that selling district heating is not a viable proposition. A meat-freezing plant using absorption refrigeration might sound attractive if there were nearby sheep stations, a railroad, or (forgive me, Kiwis) decent roads. There are not. Water at 100°C would be of little use to a pulp mill.

During the past decade the New Zealand government has sponsored many research and development projects that are aimed at better utilization and higher efficiency at the Wairakei plant. On the former front the results have not been too encouraging except, perhaps, for the silica treatment process (*8*).

One point in Barnea's letter is correct. I *was* unaware, when I wrote the article, that waste water is routinely reinjected at the Otake field in Japan. The journal which announced this encouraging news (*9*), while carrying a 1974 date, was published in 1975. It arrived in Princeton on 17 March 1975—just about the time Barnea wrote his letter.

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References and Notes

1. W. A. J. Mahon, personal communication.
2. R. E. Belin, *Geochim. Cosmochim. Acta* **16**, 181 (1959).
3. A. K. Stoker and P. Kruger, "Radon in geothermal reservoirs," paper VI-42 presented at the Second United Nations Symposium on the Development and Use of Geothermal Resources, San Francisco, Calif., May 1975.
4. *Environmental Analysis of the Uranium Fuel Cycle*, part 1, *Fuel Supply* (EPA-520/9-73-003-B, Environmental Protection Agency, Washington, D.C., 1973).
5. In the legal profession, ignoratio elenchi is invoked whenever a barrister follows the immortal advice "No case. Abuse the plaintiff's attorney."
6. T. G. N. Haldane and H. C. H. Armstead, *Proc. Inst. Mech. Eng. (U.K.)* **176**, 603 (1962).

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7. R. C. Axtmann, "Chemical aspects of the environmental impact of geothermal power," paper IV-2 presented at the Second United Nations Symposium on the Development and Use of Geothermal Resources, San Francisco, Calif., May 1975.
8. H. P. Rothbaum and B. H. Anderton, "Removal of silica and arsenic from geothermal discharge waters by precipitation of useful calcium silicates" *ibid.*, paper IV-13.

Japan Geothermal Energy Association, *Geothermics* **3**, 122 (1974).

Citation Analysis Studies

Citation analysis reflects the real world of science, not a fantasyland where all scientists' work is equally valuable, where there is no scientific elite and no mediocrity, or where scientific results are directly proportional to money spent.

It is ironic that Nicholas Wade, in his otherwise excellent article on citation analysis (News and Comment, 2 May, p. 429), neglected to cite any of the relevant literature. It is equally ironic—and significant—that subsequent critics of citation analysis (Letters, 13 June, p. 1064) ignore the wealth of published information on citation analysis (*1*), in which each of their points has already been assessed.

Those who read this literature will find that citation analysis is not without its pitfalls, but that anomalies or abuses have a very small effect. Statistical routines have been developed to deal with derogatory and self-citations, multiple authorships, the stature of the journal in which an article appears, and unusual techniques papers. In addition, a confidence statement appropriate to statistical indicators is usually included in citation analyses.

Original, informed criticism of citation analysis is welcome.

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References

1. D. J. de Solla Price, *Science* **149**, 510 (1965); A. E. Bayer and J. Folger, *Sociol. Educ.* **39**, 382 (1966); J. Margolis, *Science* **155**, 1213 (1967); C. R. Myers, *Am. Psychol.* **25**, 1041 (1970); A. M. Hall, *The Use and Value of Citations—A State of the Art Report* (Report R70/4, Institution of Electrical Engineers, London, 1970); W. O. Hagstrom, *Sociol. Educ.* **44**, 375 (1971); J. P. Martino, *IEEE (Inst. Electr. Electron. Eng.) Trans. Eng. Manage.* **EM-18**, 146 (1971); A. J. Meadows and J. G. O. O'Connor, *Sci. Stud.* **1**, 95 (1971); J. R. Cole and S. Cole, *Social Stratification in Science* (Univ. of Chicago Press, Chicago, 1973); A. J. Meadows, *Communication in Science* (Butterworths, London, 1974); J. R. Cole and S. Cole, *Science* **183**, 32 (1974); H. Small and B. C. Griffith, *Sci. Stud.* **4**, 17 (1974); B. C. Griffith, S. Dey, J. Stonehill, *ibid.*, p. 339; J. A. Virgo, thesis, Graduate Library School, University of Chicago (1974).