

continued from page 15

Hooper, IEEE Trans. Power Delivery 4, 465 (1989).

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1/92

The letter from Robert Adair and the reply by Robert Becker started me to rethinking the question of possible adverse effects of extremely-low-frequency fields, and especially their magnetic component.

The references to such effects that I had previously seen usually concerned the danger of fields from high tension lines. I had therefore been skeptical because of the inability of electric fields to enter the body. The same, however, does not apply to magnetic fields. In fact, even very small varying magnetic fields can affect some organisms. R. W. Murray found that the electric organs of certain fish could respond to electrical fields of less than $1 \mu\text{V}/\text{cm}$, which he induced by moving a small magnet that he held in his hand at a distance from the aquarium.¹ Similar responses have been observed by others in a variety of aquatic species; it is evident that the response results from a stimulus far below the Boltzmann kT/e "limit." (Alan L. Hodgkin and Andrew F. Huxley² encountered a similar but less severe problem in their analysis of the sensitivity of squid axons.²) I resolved these apparent anomalies by a statistical analysis of the stochastic processes involved,³ in which Ca^{2+} may play an essential role.⁴

The fact that low-level 60-Hz magnetic fields *could* cause problems is not, however, evidence that in fact they do so!

References

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1/92

ADAIR REPLIES: The comments by Geoffrey Landis and by Franklin Hutchinson are illuminating—and correct.

Franklin Offner refers to the detection of very-low-frequency fields of $1 \mu\text{V}/\text{cm}$ by fish and to the results of the beautiful Hodgkin-Huxley experiments as demonstrating responses "below the Boltzmann kT/e " limit. Actually, large sharks detect electric fields of $1 \mu\text{V}/\text{m}$, 100 times

smaller, by integrating responses over large distances and large numbers of detectors (the ampullae of Lorenzini) in a manner that does not violate kT constraints.

Offner's "Boltzmann limit" on electric fields is better written as kT/q , where q , the charge carried by the ion, is known to be sometimes as large as $7e$ or $8e$. Moreover, the characteristic transmembrane potential differences that Alan L. Hodgkin and Andrew F. Huxley found to elicit significant current changes were of the order of 25–50 mV, while $kT/e \approx 25$ mV; hence there is no contradiction between their results and the kT limit.

Antony Fraser-Smith appears to argue that any artifact not found in precisely the same form in nature is, *per se*, highly suspect. I disagree.

Then, in the course of a remarkable statement to the effect that 60-Hz fields increase our susceptibility to fields at higher frequencies, he says that 60-Hz fields "near an electrical appliance" might generate "increases of the order of 10^9 in these peak amplitudes [of higher-frequency fields]." He supports that unusual conclusion by the remark that "there is no need for me to explain [this] to readers of PHYSICS TODAY." But this reader, who lives in the Earth's field, which is much larger than most environmental fields, is puzzled—and incredulous.

Fraser-Smith then says the Federal government has "dropped the ball" on the issue of research on the biological effects of electromagnetic fields. The government has supported, and is supporting, appreciable research on the effects of electromagnetic fields on biological systems. Whether the support is too much or too little must follow from comparisons with other research priorities.

However, I would argue that much of the research support, including that provided by the Electric Power Research Institute, is badly directed.

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7/92

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To Aid Teachers, Fix the Bureaucracy

We are very impressed by the work Leon Lederman described in his Reference Frame column "Of Scientists and School Systems" (May, page 9). His enthusiasm and the depth and scope of the Teachers' Academy of Mathematics and Science will undoubtedly have a positive impact on the teaching of math and science in the Chicago schools. Lederman

speaks highly about the contributions of many of his colleagues in higher education; however, he mentions only in passing the work of master teachers at his academy. We hope that he will make full use of the expertise of teachers in the Chicago system. The lack of appreciation of the work of fine teachers is one of the shortcomings of many otherwise noble efforts by the university community.

Lederman says rightly in his article that the educational bureaucracy must ultimately be fixed. We believe that this cannot wait and must be done simultaneously with the training and support of teachers. A major part of the current problem is the conditions under which teachers teach. They have too many students, excessive nonteaching duties, few dollars for materials, little or no support for laboratory work, and pressures resulting from inappropriate curriculum guidelines and testing methods. If these conditions do not change, Lederman's efforts may not have the long-term impact that they should.

Finally, it is most important that the academic community not overlook one of the primary causes of the poor preparation of teachers: Many of the science and mathematics courses that prospective teachers take in college transmit only factual knowledge and are lecture based. These courses do not provide the necessary depth of understanding of what science and math are, nor do they engage students in the process of scientific inquiry. The heavy emphasis on research for promotion and tenure and the few rewards for excellence in teaching discourage necessary innovations. We believe it is the responsibility of the academic community to look to its own problems as well as those of the schools.

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6/92

LEDERMAN REPLIES: The comments of Viki Weisskopf and Karen Worth, reasonable and wise, are so typical of attitudes we have often met that they are worthy of reaction. There are so many experts, so many initiatives and so many strongly held opinions, for example: "Why bother with teachers if you can't fix families?" or "But the streets are unsafe" or, as Weisskopf and Worth say, "this [fixing the educational bureaucracy] cannot wait and must be done simultaneously."

What are we to do? Wait? Why

LETTERS

must it be done simultaneously? Anyone who is part of academia must know that academia doesn't change easily. Meanwhile millions of children are hostage to the low level of math and science teaching. If you influence one teacher, you affect thousands of children. Should we abandon our efforts until this, that and the other precondition, sensible as they are, are satisfied? The point of my column was to urge fellow physicists to go out and get involved in the schools—at any level, in any effort. Each effort is a ripple, and enough ripples can make a tidal wave.

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6/92

Can a Tokamak Breed Enough Tritium?

The article "Progress Toward a Tokamak Fusion Reactor," by J. Geoffrey Cordey, Robert J. Goldston and Ronald R. Parker (January 1992, page 22), left me puzzled. The breeding of tritium reminded me of the story of Baron von Münchhausen's pulling himself out of a swamp by his own hair. My reasoning, based on the descriptions in the article, is as follows: For one D + T reaction you get one neutron. One neutron can produce one tritium nucleus during breeding. Since according to the article a 1000-MW station requires on the order of 1.5 tons of tritium a year, and the inventory of tritium is a few kilograms, this tritium inventory would have to be recycled several hundred times a year. Even with a breeding efficiency of 90% you would run out of tritium well before the first year of operation was over. I know that the above calculation must be wrong, because too many scientists work on a reactor of this kind, but I can't see the error.

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1/92

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CORDEY, GOLDSTON AND PARKER REPLY: Apparently our description of how tritium fuel is to be regenerated from fusion neutrons was not detailed enough. In fact the reactor blanket will include *neutron-multiplying* materials such as beryllium or lead so that the net "breeding ratio" can be greater than 1; typically one will be aiming at an adjustable ratio of up to 1.1. The yearly tritium burn-up in a 1-GW_e D-T reactor would be about 170 kilograms. (The 1 tonne per year of deuterium quoted in the article is for a 1-GW_e D-D reactor.) In contrast

to a fission breeder, in a fusion reactor the fuel inventory is very modest, so the time it takes to produce the extra tritium required to start up a new reactor can be made quite small.

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6/92

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'Japan: Not an Energy Efficiency Model'—Not!

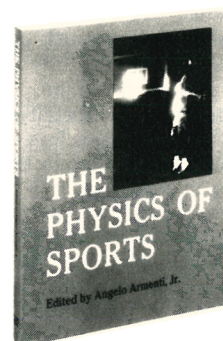
I suspect you will receive a flood of letters in response to the Opinion piece in February 1992's issue (page 95); still, "Japan: Not an Energy Efficiency Model," by Milton Searl and Chauncey Starr, proved too provocative for me to resist adding to that presumed deluge.

Searl and Starr attempt to convince the reader that although the US uses 2.4 times as much energy per capita as Japan, there is really no reason nor even a viable course of action to reduce this ratio substantially. The numbers quoted in their column actually make it worth reading; it is the interpretation—the "spin"—they give those numbers that makes it so objectionable. In short, the "reasons" they give for each form of massive energy waste in this country, and even more their attempts to reinterpret the data until they look agreeable, are worthy of a public relations team trying to whitewash an industry with a bad reputation (maybe a fair description of the goal of the column).

Let me give some examples: Searl and Starr first point out that the conversion from primary to secondary energy forms is the largest single sector of energy use in the US, and that this conversion is done more efficiently here than in Japan. That may be true, but is of course completely besides the point: This part of the energy budget is, after all, proportional to the sum of all other sectors and thus should be factored into them. (If we waste energy in transportation, we're also wasting a proportional amount in the conversion process needed to produce the fuels in the first place.)

From that perspective, the second-largest sector of energy use in the US cited by Searl and Starr, namely transportation, is really the largest one. And it is this sector where indeed most of the waste occurs: 3.6 times as much energy per capita is

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