ime, the booth keeper should talk to all nterested people. Often more aggressive, knowledgable persons dominate the conversation. Discussion with a single person should be limited to five minutes o give others an opportunity to ask questions or discuss other problems.

More effective displays are suggested. n addition to the sign containing the booth number, title and list of authors, another should state the purpose of the experiment or theory and give the principal results. Investigators should emphasize their major points with a large poster. If the displayed material is reasonably complete, booth holders will be able to use their time for answering questions. An "out-to-lunch" sign is needed for each booth announcing the presenter's time of return when visiting other booths.

One participant recommended that the services of a consultant in visual-aid techniques be acquired with the aim of producing a short pamphlet containing suggestions as to how booths might be most effectively manned.

The results of our experiment with the booth sessions at the IX ICPEAC indicate that they are effective in facilitating informal but intense discussions between specialists in a particular field.

This type of session is not a substitute for the more conventional short presentation to a larger audience. Booth sessions have the most value when scheduled as auxiliary sessions, with contributors signing up for booth space on a voluntary basis. There seems to be no clearcut advantage in arranging scores of booths rather than many parallel sessions. (A more complete version of this report may be obtained directly from the author.)

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6/7/76 *Raleigh, N. Carolina*

Re-inventing the fireplace

In "Efficient Use of Energy" (August 1975, page 23) the authors offer suggestions for improvement of the energy efficiency of home heating. They point out that "economy involves locating the crucial stage of energy conservation at the site of its end use." And they suggest that fuel be burned in "room radiators" at low temperature, by use of some type of catalyst yet to be developed.

It seems that this is a re-invention of the fireplace, but with unnecessarily sophisticated and inefficient modification to low-temperature operation.

The authors themselves concede that high-temperature heat sources offer better second-law efficiency than low-temperature heat sources. It is far from clear why low-temperature operation is recommended.

A further great advantage of high-temperature operation derives from the fact that at high temperatures, one can produce radiant heat with increasing efficiency; and radiant heat offers a double advantage over convective heat from furnace-based systems. Radiant heat can be beamed toward the user[1], and it can be absorbed directly by the user. Convected heat only controls the rate of heat loss by the body, and requires the heating of large masses of air and of structural interiors merely to keep a thin layer of air next to the skin within the zone of comfort.

Reference

1. L. Cranberg, "Slot-Stable Flame with Hohlraum Radiation Pattern," Bulletin, APS, Sept., 1975, p. 1183; "The Physicist's Fire," Time Magazine, Dec. 1975, p. 52.

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More on coal vs. fission

In his letter (June, page 77) on the hazards of air pollution, J. H. Ray compares the radioactive dispersion of fossil-fueled and nuclear-fueled power plants, expressed in quantities proportional to the electric power produced. He concludes that nuclear reactors emit 5×10^2–10^6 times less radioactivity than fossil-fueled power stations. Because it has been illustrated that the most important components of coal pollution, Ra^{226} and its daughters, represent not only a local but also a long-term problem (Zbigniew Jaworowski, Health Phys. **20**, 499, 1971), this letter will illustrate that Ray's argument is based on an irrelevant comparison that is common in the nuclear controversy. In his author's comment, J. Devaney (page 78) extends this reasoning erroneously.

When comparing the radioactive dispersion of pollutants in the atmosphere due to 1000 megawatt years of electricity production by a coal or nuclear power plant, one has to take into account all releases during the whole fuel cycle and not only those during the power-production phase.

According to Jaworowski, the radium activity from coal varies from 0.001 to 1.3 picocuries/gram, depending on the type and origin of coal. From his data, we calculate that a 1000-MWe coal plant should produce yearly a minimum of 4.7 microcuries (for 99.8% dust-filter efficiency and 0.001 pCi/gm coal specific activity) to a maximum of 570 millicuries (75%, 1.3 pCi/gm). The average for European and Asian coals varies between 1.4 and 170 mCi.

Around coal plants the radium activity can be considerable, and a worldwide dispersion is noticed. However, this pollution can easily be reduced by classical control techniques. The efficiency of the dust collector can decrease the radium

release by a factor of a hundred.

A 1000-MWe nuclear reactor releases practically no radioactivity, but radium and its daughters are produced in the nuclear fuel cycle during the treatment of uranium ore in the mining operation. According to P. H. Pigford (Ann. Rev. Nucl. Sc. **24**, 215, 1974), for each 1000 MWe years of energy production, there is released 56.7 Ci of Rn^{222} and 22.6 mCi Ra^{226} to the atmosphere—51 mCi Ra^{226} as liquid waste and 56.6 Ci Ra^{226} is created as solid waste. During the conversion of uranium oxide to hexafluoride another 250 mCi liquid waste is created.

The released dust in the mine contains uranium and daughters as Th^{230} and Ra^{226}. Almost all the radium in the ore moves to the tailing piles, which represent a considerable source of radium and radon activity. In practice it is very difficult to prevent the emanation of the radon gas. An EPA study ("The Environmental Analysis of the Uranium Fuel Cycle; Part III, Fuel Supply," EPA-520/9-73-003-B 1973) gives a detailed analysis of these problems, in agreement with Pigford's data. From this study one can derive that for each 1000 MWe year's LWR energy production, about 56 Ci of Ra^{226} arrives at the tailing piles. The radium dispersion in the atmosphere is dependent on weather conditions and pile situation. About 11 mCi/year of Ra^{226} is released as unsoluble aerosol; the same amount is seeping into the river waters. Out of the radium stock of the tailing piles, 20 to 80% of the noble-gas daughter Rn^{222} is actually released to the atmosphere, yielding about 56 Ci/year for each 1000 MWe years. It is not radon itself but its daughters, such as polonium and lead, that represent a high risk of fatal lung cancer. According to the EPA, there was in 1973 in the US an inventory of about 56 000 Ci of Ra^{226}. The Rn^{222} emanating from all piles represents a total release of 150 000 Ci/year of radon gas.

Comparing the above-mentioned data for nuclear and classical release of Ra^{222} for a unit of 1000 MWe years of electricity production, we can see that they are of the same order. The potential stock of radium activity at the uranium mine, however, constitutes a Rn^{222} (and daughters) pollution source with orders of magnitude greater risk than the direct radium release. (A reduction can only be achieved by expensive thick sand covers.) Because the mine tailings contain Th^{230}, the Ra^{226} stock will be maintained by decay; so the radon source will remain constant for thousands of years. Hence Devaney's reasoning that after 500 years the radioactive toxicity from coal ashes is greater than all fission wastes save Pu^{239} is erroneous.

Finally I would suggest, alternatively to Ray and Devaney, that more research effort should be devoted to the combined effects (that is, climatological) of chemical and nuclear pollution. This approach could also help us to see pollution problems in a more global ecological context and prevent an out-of-place controversy on the extremely valuable APS reactor safety study.

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9/24/76 *Belgium*

AUTHOR COMMENTS: I believe G. Eggermont has misunderstood the significance of my response to J. H. Ray, has violated his own dictum of completeness, has unintentionally left some false impressions, and has unfortunately made accusations of error when perhaps he meant incompleteness. Nonetheless, from the tenor of his letter I think there can be agreement on the major power issues.

My remark ". . . that after 500 years the radioactive toxicity from typical coal ash is greater than that of *all* the fission wastes (i.e. fission products) save plutonium-239, which is recyclable as reactor fuel," was derived from the calculations of Douglas Muir.[1] See also Richard Wilson's statement.[2] I would be most interested of course in any correction that Eggermont would care to make in this estimate, but I note that in his letter he does not address the accuracy of this remark, much less disprove it.

How much to respond to a letter is largely a matter of taste, and *de gustibus non est disputandum* (with apologies to Jim Tuck and all classicists). I chose at the time to confine myself to the point Ray raised about comparative radioactive effluents of coal versus nuclear power plants. One should not be misled, as Eggermont apparently was, that Ray's point should be taken as primarily a total hazard contribution. Clearly not, for then the principal hazards of coal, namely chemical and non-nuclear physical, would so overwhelm the coal radioactive hazard as to leave it negligible except at very long times.

Rather the significance of our comparisons, as I see it, is one of perspective. That is, even confining ourselves just to regular radioactive emissions, the coal-fired plant turns out to be much worse than a fission reactor, as Eggermont concedes, and moreover its effluent will remain very radioactive at very long times, even greater than most fission wastes, about which there is presently much concern. Hence it follows, for example, that the laws restraining radioactive emission should either be relaxed for nuclear plants or enforced equally for coal plants; and, in addition, concern for radioactive-waste hazard persistence at very long times is either overdrawn or must be applied to coal as it is now to nuclear. At present (nationally and in the state of New Mexico), to my knowledge there are

no limitations whatsoever to the emission of any amounts of radioactivity in connection with coal burning, nor any restrictions on radioactive waste disposal from coal-fired plants, whereas from fission plants the limitations are extreme and—in comparison to other risks we routinely accept or are necessarily exposed to—absurd.[3] So much for the significance of Ray's point and of my response.

As to the radioactivity in the mining of uranium, Eggermont's point is not new and is accounted for in complete assessments.[4] Allowing his point to stand without including the total comparative risks in mining both fuels is misleading, serving to favor coal power. As a matter of fact, uranium plus daughters are also a hazard in coal mining,[5] but more important to the coal miner by far is the black-lung disease. The total ratio of fatalities from mining and milling of the two fuels, coal to uranium, are somewhat uncertain[4] but are approximately 60 to 1 for the same electric power produced. The ratio of disability days, coal to uranium, is 10 to 1. Of the fatalities in uranium mining and milling noted above, the fraction caused by radioactivity is only one part in 174. Thus the part of the fuel cycle that Eggermont has chosen to study is, when all hazards are accounted for, actually greatly favorable to fission power. Of course, concentrating on one part of a fuel cycle can be made to show least hazard for either fuel for that part. Selecting just the fuel preparation post-mining would show coal to be of negligible hazard, because, unfortunately, it usually undergoes zero processing no matter how impure (except for sulfur). Indeed the Farmington, New Mexico coal has 20% to 25% impurities and is burnt with no preparation or washing whatsoever. Alternatively, selecting the transportation post-milling part of the fuel cycles would highly favor uranium because of the enormous energy-to-weight ratio of uranium versus coal. In short the meaningful comparison to be made is between the respective total hazards.

One estimate[4] for the ratio of fatalities from the total generation cycle gives numbers in the range 60 to 1 to 220 to 1 for coal power-generation fatalities to fission power-generation fatalities for the same electric power generated. The ratios for the general public have been put as high as 18 000 to 1, coal to nuclear.[6] My incomplete studies indicate that many of the coal-fired toxicants have not yet been considered, that synergetic effects are not included, nor are the toxicities assessed properly,[7] so that the above figures could be considerably larger, therefore more favorable by far to the generation of power as much as possible by fission. On the other hand it must be acknowledged that, in spite of the excellent fission power-plant studies thus far reported, for example the APS reactor study and the Rasmussen study, some citizens postulate yet greater probabilities of disastrous nuclear accidents. In this respect the reader must judge for himself, but in making comparisons I note that the coal hazards are largely taken from actual experience, directly or inferred, and are not unrealized probabilities.

Although in the sense he uses it he is strictly correct, Eggermont's remark, "However this pollution [radium activity from coal] can easily be reduced by classical control techniques," is seriously misleading for particulates. In a nutshell the reason is that for the transport into the biosphere in general and into the human lung in particular, the chemical reactivity, the irradiation, as well as the efficiency of *ex post facto* control devices, all depend critically on particle size. Thus numbers like "99.8% dust-filter-efficiency" are meaningless, for these are weight-ratios. Consider for example a 50:50 particle mix of say 100-micron and 0.5-micron particles. If all the 100-micron particles were removed from the stack gas one would have a "dust-filter-efficiency" of 99.9999875%, but the 100 micron particles (which are in fact easily removable by "classical control techniques") progress little in the atmosphere, are readily washed out by rain and by nucleation, are readily trapped in the nasal and bronchial passages and removed, have a small surface-to-volume ratio, and in short, are generally innocuous.

The fine particulates are quite another matter. They are inefficiently removed by precipitators and the like, and their rate of fall in the atmosphere is negligible, especially so in normal turbulence. The efficiency of rain removal begins to drop at sizes below about 4 microns. They are nucleated out in only a small volume of space-time, especially in the arid Southwest. Human-lung particle-retention peaks in the 0.5 to 1.1-micron range at an amount of over 50% retention; other estimates have been as low as 25% lung deposition. The surface-to-volume ratio, hence chemical reactivity and adsorbtivity, is enormous and some fly ashes are actually shells rather than solids. It is known that the presence of particulates synergistically increases the toxicity of gases such as SO_x a hundred-fold, the effect apparently being adsorption of gas on particle plus higher lung retention of the particle [my explanation]. Being near the wavelength of light, these particles, pound for pound, scatter and hence obscure the most. Thus the fine particles that efficiently escape the control devices do all the damage, yet they have effectively none of the weight. This comparison is not merely academic, for a notorious example is the effluent from the Four Corners (Farmington, New Mexico)

continued on page 65

continued from page 15

coal-fired power plant (order of 10^{23} submicron particles per day), which alone pollutes vast areas (observed at 100 000 square miles) of a four-state region. The airborne particle-size distribution peaks at 0.8 microns and is composed of spherical shells.

To add to the technical difficulties of control of the highly damaging submicron particles one must take practical note of the political and economic probabilities of getting even the most modest state-of-the-art control. These coal-fired power plants represent on the order of $200 000 000 investments, now much more, (2000 MWe). They hire many people; they financially and politically dominate whole regions and they vigorously protect their profits and freedom from governmental control. They have every economic incentive (and large ones at that) to do so. For instance, I believe the maximum air-pollution fine in New Mexico presently is $1000 per event (not per day, or per pound of pollutant, or per injury). I leave it to the reader's imagination as to how often this fine has been imposed on so rich and powerful an entity in a poor, lightly educated, job-hungry state like ours.

In sum, coal-fired pollution control is so bad and is foreseeably so bad, that one might only be a little wrong to say that pollution control is nearly as bad as no control at all. It *has* been said by many that the laws are but "a license to pollute." So Eggermont's confidence in "classical" controls and in 99.8% by weight removal is unfounded.

However, there are prime areas of our power problem in which we can all agree. Of the economically viable fuels it is clear that we want to utilize the least hazardous and polluting. At the present time and for the near future, the only large-scale alternatives are coal and fission. The hazards of the latter have been highly studied and publicized. We need to do the same for the former, coal. Indeed, many governments are rushing post haste to place severe restrictions on fission power that will necessarily make coal power more attractive to power-plant executives. How if coal be worse? How if coal be very, very, much worse?

Consequently I submit that the question before us is not: "Is fission power safe?" but rather: "What is the comparative hazard of the whole cycles of the two alternative fuels?" Most needed are further studies of coal hazards. Least needed, because we have already many studies in hand and because of the misuse already being made of them by the public and others, are the non-comparative publication of further fission-cycle safety studies I have tried to warn against.[7] Above all, because the public, the state and national governments and the power-plant executives are deciding right *now* on the fuel cycles that will be used during the remainder of the lives of most of us, we need complete comparative studies, however approximate, however premature, so long as they are timely (with apologies to the authors of the magnificent studies already made). To avoid misuse, I further recommend that every specialized study in these fields include a statement, as complete as possible, indicating the net effect of the findings on the *ratio* of total hazards of coal to nuclear fission power for the same produced electric power.

JOSEPH J. DEVANEY
11/22/76 *Los Alamos, New Mexico*

References

1. Douglas Muir, private communication, 1975. I am indebted to Muir for his kindness.
2. Richard Wilson, statement to a committee of the California Assembly, Nuclear News, February 1976; page 55.
3. Bernard L. Cohen, "Environmental Hazards in Radioactive Waste Disposal", PHYSICS TODAY, January 1976; page 9.
4. D. J. Rose, P. W. Walsh, L. L. Leskovjan, "Nuclear Power—Compared to What?", American Scientist, May–June 1976; page 291.
5. See, for example, R. L. Rock et al, "Evaluation of Radioactive Aerosols in the United States Underground Coal Mines", US Department of the Interior Report 1025 (1975).
6. L. B. Lave, as quoted by N. Rasmussen, lecture, Los Alamos Scientific Laboratory, c. 1974.
7. J. J. Devaney, PHYSICS TODAY, December 1975, page 9.

In praise of engineering

I have followed the discussion on engineering physics in PHYSICS TODAY and the *Forum Newsletter* with some interest, having been a 1962 graduate of the program at the University of Oklahoma. From my perspective of today, I could not be more pleased with the program I followed there or the education I received. I would personally urge all physics departments that have a School of Engineering available to explore seriously the option of an engineering-physics curriculum.

I think of myself as both a physicist and an engineer. I have since received a Master's degree in physics (from the University of Washington, a top-notch department in my opinion) and am a registered Professional Engineer. I feel equally at home with "charm" quantum numbers or steam tables. My work assignments over the years have almost always been in the general area of applied research, ranging from electromagnetic interference investigations to almost basic research in solid-state physics. Following a personal interest, I have moved into the field of air-pollution control over the past few years. In my studies of atmospheric optics and the behavior of aerosol streams I constantly need many of the things I learned in classical mechanics, electrodynamics, or statistical mechanics. I also find I use what I learned in mechanical and chemical engineering every day. I am certain that there must be many similar situations where physics and engineering intersect and engineering physicists could make an important contribution.

T. G. Stinchcomb (September, page 15) wonders about the equivalency of the training that physicists and engineering-physics majors receive at Oklahoma. I will admit that, partly because I took some classes (such as thermodynamics and mechanics) in the engineering school rather than from the physics department, I did have some problems later in graduate school. But I did overcome them and I would do it again in just the same way. I did learn a lot of engineering in my engineering classes, which has served me well. Stinchcomb also wonders about the job market for engineering physicists. I have found that I generally have an easier time finding openings and am generally offered the same or better salary than friends of mine who are physicists (even though they are mostly brighter than I). I believe that is because employers think that with my engineering training I will produce something they can use (although you and I know that it is the physics I learned that enables me to deliver). There are many fields of applied physics that have been ignored by physics departments. Does your department offer undergraduate classes in physical optics, acoustics, hydraulics, high-pressure physics, and so on? Even without an affiliation to an engineering department, such a hard look at the curriculum would be a good place to start.

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TWT, mags still kicking

I found the article on high-power microwave generation (November, page 18) quite interesting. I was, however, a bit miffed by one statement: "By reviving the old devices (traveling-wave tubes and magnetrons) developed a quarter of a century ago . . . ." I am an engineer working in traveling-wave tube R&D and I would like to inform you that the TWT business is quite healthy with no reviving needed.

TWT's find wide applications in medium and high-power microwave amplifiers. Solid-state devices cannot even approach the kinds of performance we achieve and there is still a lot of exciting R&D going on, some of it even sponsored by NRL. As recently as 1970 an article was published in the *IEEE Transactions*