which is consistent with the "linear hypothesis," does not go through the origin (zero cell killing at zero dose). If the data we presented are carefully examined, it is true that there might also be zero cell killing at about 6.0 ± 7.7 rads when the best-fitting straight line is extrapolated to zero cell killing. This extrapolation was also pointed out in the legend to our figure 2 (*1*), which stated that a best-fit straight line not constrained to go through the origin intercepted the ordinate at 1.018 ± 0.022 at zero dose, not 1.000 as the no-threshold hypothesis would imply. The explanation for this extrapolation is a simple one, and we should probably apologize for only referring to it (*3*) and not mentioning it explicitly in our report. At the time of irradiation up to 4 percent of the colony-forming units in the cultures contained two cells instead of just one so that the measured survival is that of the two populations. Since 96 percent of the cells were single and 4 percent of the colonies had two cells at the time of irradiation the survival S at low doses is given by

$$S = 0.96\, e^{-CD} + 0.04[1 - (1 - e^{-CD})^2] \quad (1)$$

where D is dose, and the coefficient C has the value we reported. Equation 1 is conceptually more consistent with the experimental design than the relationship

$$S = S_0 e^{-CD} \quad (2)$$

which also extrapolates to $S = 1.018 \pm 0.022$ at zero dose, or the relation

$$S = I - CD \quad (3)$$

suggested by LePage.

The value of reduced χ^2 for the fitting of Eq. 1 was found to be 2.3, but when we attempted to fit threshold-dependent functions suggested by Rydin, LePage, and other respondents, we found χ^2 values between 3.0 and 4.0. We did not consider the possibility of ignoring any of the data points as some other respondents wished to do.

Concerning the meaning of "high" and "low" doses, in the context of sensitive biological end points such as malignant transformation (*4*), a dose of 20 rad is high. Cell transformation can be detected around 1 rad because it is measured above a small zero-dose background incidence. Somatic cell survival, whether in vitro or in vivo, must be measured as a difference between two large numbers. For example, to measure cell survival after 5 rads, which we predict to be 98.5 percent, would require the counting of at least 10^5 colonies, irradiated and control, to obtain statistical significance. Beyond a priori statistics, superimposed technical error limits make such a measurement nearly impossible. Since our result, which improved substantially on the statistics presented in early work (*5*), did not change the original conclusion that cell killing is a linear function of dose at low dose, we did not commit research resources to further refinements.

We are delighted that Rydin and LePage and others have been stimulated by our study to give critical thought to the issue of biological dose-response relationships for ionizing radiation effects.

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23 June 1980

High-Grade Fuels and Biomass Farming

Weisz and Marshall (*1*) have presented a distorted view of both the energetics and economics of ethanol production via biomass fermentation. Their conclusion, that with current technology ethanol production represents a net consumption of fuel, results from use of an unrealistically high processing energy and neglect of energy credit for the distillers' dry grains. There are firms currently designing and constructing fermentation ethanol plants (*2*) with processing energy requirements in the range of 1.71 to 0.46 GAL (energy-equivalent gallons of fuel) (*3*) as compared to the value of 3.92 GAL used by Weisz and Marshall (part B in their figure 4). Although they allowed a credit for distillers' dry grains in their economic analysis, they ignored this in their energy analysis. Inclusion of this credit would reduce the cultural energy input, A, by one-third, resulting in A = 0.75 in their figure 4. Fuel efficiency must, indeed, be incorporated into the energy analysis, but for gasohol, the alcohol-containing motor fuel most likely to be implemented, the literature contains conflicting accounts (*4*). Weisz and Marshall in considering the best possible case, equal fuel efficiencies (miles per gallon) for ethanol and gasoline, arrive at the conclusion that "the system would remain a net fuel consumer." However, with the more realistic figures cited above the best possible case for current technology results in a net fuel production ranging from 0.14 to 1.39 GAL.

Under the subheading *Proposed improvements* their "most optimistic case" is subject to the same flawed analysis. Using the energy credit for distillers' dried grains and fuel equivalency (equal miles per gallon) for ethanol and gasoline one obtains 4.68 GAL resulting from an input of 1.33 GAL, a net production of 3.35 GAL as opposed to their result of 1.1 GAL. Even when fuel efficiency is based on volumetric energy content (*5*) the results are 3.1 GAL resulting from an input of 1.33 GAL for a net production of 1.77 GAL.

Even more serious was their failure to use insights available through the second law of thermodynamics. They ignored the quality of energy and presented their results simply in terms of GAL's (Btu's). Conspicuously absent is the realization that the ethanol-via-biomass process requires mainly low-level heat for such tasks as cooking, by-product drying, and distillation. Today, many well-managed petroleum refineries and chemical-manufacturing complexes have an abundance of low-pressure steam that could be used for ethanol production. Also, cogeneration of electricity and low-pressure steam would be effectively incorporated into future ethanol production facilities. Whether these sources of low-quality energy will be utilized, of course, depends on the existence of the necessary economic incentives; however, a proper energy analysis should recognize this potential advantage.

A strange brand of economics, based on net fuel production, was used to arrive at an excessively high cost for ethanol which was referred to as "consumer outlay." This economic artifact was then compared with the market price of methanol and coal-derived fuels leaving the reader only to conclude that ethanol manufacture is prohibitively expensive. All processes are subject to efficiencies (first or second law based) less than unity; however, because of "free," and thus uncounted, solar energy the agricultural operation that produces biomass returns us more energy than expended. Thus, a total process that includes a bio-

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mass production step can exhibit a practical net production of energy, or fuel, whereas processes such as coal conversion, methanol production from natural gas, and even the refining of petroleum to produce gasoline must be regarded as consumers of energy. A cost of net fuel production can be calculated for the former process, but not for the latter. Therefore, a comparison of cost of net alcohol fuel production with the market price of the other fuels is not consistent and distorts the economic picture.

Instead of accomplishing their stated intent "to aid in future research and development," their conclusions, if allowed to stand unchallenged, could do serious damage to that cause.

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References and Notes

1. P. B. Weisz and J. F. Marshall, *Science* **206**, 24 (1979).
2. For example, Bohler Bros. of America, ACR Process Corp., Chemapec, Inc., and Raphael Katzen Associates International. See also F. F. Hartline, *Science* **206**, 41 (1979).
3. One GAL = 113,000 British thermal units (Btu).
4. One test showed slightly better fuel efficiency for gasohol [W. A. Scheller, and B. J. Mohr, *Chem. Technol.* 7, 616 (October 1977)], another test showed essentially equal fuel efficiencies [Department of Energy, *Interim Report: Gasohol Test Vehicles* (Energy Research Center, Washington, D.C., August 1977)], while another reports slightly poorer performance for gasohol [V. Hofman, *Gasohol* (Cooperative Extension Service, North Dakota State University, Fargo, May 1979)].
5. Ethanol contains 0.67 times the fuel energy of an equal volume of gasoline.

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Current technology means technology as generally practiced, not as conceived or proposed. Also, Kyle should have noted that we (*1*) used "current technology" as just one anchor point of the discussion. We pointed out that improvements are being made; we carried the analysis and discussion to the other anchor point, namely, to the limit of no consumption of high-grade fuel by the distillery.

The statement that we ignored the energy credit for distillers' dried grains is erroneous. We discussed this question in detail (*1*, p. 25, the last full paragraph). Also, the gross to net fuel productivity ratio [see figure 6 in (*1*)] includes this credit.

We realize that advocates of gasohol staunchly adhere to the assumption of an automobile mileage performance per gallon equal to or better than that of gasoline, in spite of the 3.4 percent lower energy content of the gasohol mix. This impression was created by the "Nebraska test" (*2*), which was begun in 1974, and continues to be quoted. It was aided by the past practice of designing engines to a stoichiometrically "rich" mixture of gasoline and air; the stoichiometric excess of gasoline remains unburned and therefore slightly decreases gasoline mileage. A gasohol mix, with a Btu (British thermal unit) content some 3.4 percent lower and burned with the same fixed airflow can be fully consumed, and thus gives an apparently higher efficiency—by design rather than by virtue of the fuel. This artifact has been gradually disappearing since about 1974 as new car designs comply with modern environmental and mileage standards.

Statistically significant determination of differences in road mileage performance with ± 3 percent requires accurate electronic fuel flow monitoring and human bias management by double-blind procedures. The Office of Technology Assessment (*3*) judged the quantitative conclusions of the Nebraska test to be statistically unwarranted.

Kyle's suggestion that we used a "strange brand of economics," indicates that he was reading unintended sophistication into our gross versus net cost relationship. This relationship is a matter of elementary accounting: If the manufacture of a unit of a given commodity for the marketplace requires consumption of a sizable amount of the same commodity from the marketplace, then the net volume generated is decreased and its cost per unit volume is correspondingly increased. The arithmetic was demonstrated in (*1*, figure 3 and p. 24, column 3). The stated objective for the systems we analyzed was to generate a true (that is, net) increase of the commodity defined as "high-grade fuel," that is, to supplement hydrocarbon fuels that must now be imported (oil and gas).

Kyle confuses thermal efficiency (total energy in products divided by total energy input) with net productivity of the fuel commodity to be produced. No sensible conversion scheme to convert coal to methanol, gasoline, or other high-grade fuel would employ such fuel as process fuel. Indeed, if it did, it too could be a net consumer.

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