LETTERS TO THE EDITOR

COMMENTS ON "TOTAL ENERGY INVESTMENT IN NUCLEAR POWER PLANTS"

We would like to make some observations on the analysis of energy inputs and outputs involved in the nuclear generation of electricity outlined by Rombough and Koen.[1] Rather than make judgments regarding the accuracy of the empirical results presented *per se*, we simply comment on what we believe are shortcomings in the methodology employed in and the implications drawn from the analysis.

The basic misconception underlying the Rombough and Koen analysis is the contention that "An energy analysis is superior to an economic analysis because results are generally independent of time, economic instability and even the supply of energy." This is not correct. Changes in technology, efficiency of processes, reliability of plant and equipment may very well affect energy balances, as may changes in the geographical location of energy supplies or changes in the mix of such supplies between different forms of primary energy. A variety of such changes can be expected to occur over time in response to technological progress, alterations in the relative price, and availability of different energy resources, or changes in general economic or political conditions. All of these may lead to input substitutions, efforts to conserve, attempts to increase the durability of capital, and a number of other economic and technological responses—and these responses will affect physical energy balances.

Two examples of technical factors that may affect the energy balances of nuclear power are capacity factors and the influence of changes in uranium ore grades. First, the capacity factor chosen by Rombough and Koen does not coincide with U.S. operating experience for light water reactors (LWR). Evidence indicates that average reactor capacity factors have fallen well short of 80% (Ref. 2). Different assumptions regarding capacity factors are the most important single influence on the outcome of an energy analysis for nuclear power. A sensitivity analysis ranging over a number of capacity factors encompassing both possible operating efficiencies and those consistent with actual experience would be enlightening. Second, changes in uranium ore grades have been shown[3,4] to substantially alter energy requirements to support the nuclear fuel cycle, not only in terms of total energy input required but also in terms of the relative location of energy inputs in the fuel cycle. Changes in physical parameters definitely do change energy balances.

Both the increasing price and scarcity of energy and the unreliability of foreign sources of supply have led to efforts to develop indigenous sources of fossil fuels. As these increasingly marginal sources of fossil fuels are exploited, the energy required to produce a given amount of energy will increase, perhaps substantially. As the input/output data employed in the second phase of Rombough and Koen's paper account for not only the direct use of energy in producing the materials to construct a reactor, but also the indirect energy to make that energy available, total energy inputs to a given nuclear reactor will inevitably rise. Although the impact of this influence on the results of an energy analysis is likely to be small, it will nevertheless affect empirical energy balances derived using input-output methodology.

The overall contention of Rombough and Koen that energy analysis is superior to an economic analysis is subject to dispute for broader reasons. One energy development cannot be unambiguously declared superior to another simply on the basis of an energy analysis, and many other factors should be taken into account in any decision.

First, Btu's of energy derived from different energy sources cannot be frictionlessly substituted for each other as factors of production. Changes in the availability of some forms of energy will cause disruption, instability, and increasing economic as well as energy costs. As recent energy supply experience has so forcefully demonstrated, even international political instability can be translated by complex interactions within the economic system to fundamentally alter the price, the source, and the very nature of energy supplies—ultimately impacting upon energy balances. Energy analysis clearly is subject to the same vagaries, disruptions, and discontinuities inherent in the real world it attempts to reflect, as is economic analysis.

Second, Btu's of energy derived from different sources have different utility in final use; that is, they provide a service of different relative "value" to the consumer. For example, in the provision of personal transportation, gasoline has characteristics that make it more valuable than other energy forms, a difference that Btu totals do not reflect. Aside from differing in utility, different forms of energy have differing efficiencies in end-use. Thus, a Btu of one form may provide more work in any particular end-use than a unit of another form. Furthermore, these are not constant features, but vary with any given end-use.

Third, different forms of energy resource also differ in relative scarcity, and Btu totals do not reflect the premium society may well attach to the conservation of relatively scarce energy resources. In principle, given certain simplifying assumptions, the price system reflects scarcity and, at least in theory, premia expressed in dollar values can be attached to prices established in the market place to reflect the value society places upon conservation of nonrenewable resources for future generations.[5]

Finally, energy derived from different energy sources exhibits widely divergent environmental impacts, from the massive disruption involved in using coal, to a relatively clean fuel like natural gas. Except to the extent that additional energy inputs are necessary to abate these effects, Btu's do not reflect the impacts, whereas economic analysis offers a variety of well-known techniques useful in integrating environmental impacts into decisions regarding resource use.[6]

In summary, Btu totals can be made up of an infinite variety of combinations of energy sources. Each mix will have different effects on society and on the environment. Btu totals can reflect certain aspects of these impacts but for other considerations they are less flexible and ultimately less useful than dollar totals. In any case, in any given circumstance neither economic nor energy analyses should be expected to provide the sole basis for a decision, but should be weighed along with other factors.

Rombough and Koen do not give a clear description of their methodology, system boundaries, or assumptions regarding, for example, their treatment of secondary energy forms. They have omitted some inputs such as the capital inputs to the fuel cycle stages, operational inputs other than fuel to the reactor (e.g., water), support buildings and services, and transportation of materials. The relative importance of these inputs is likely small, but should be a subject of further research. In comparing nuclear generation with thermal-electric generation from coal, they have treated the coal feedstock to the latter as if it were equivalent to the uranium for the reactor. That is, the input is regarded as equivalent in Btu to the electrical output. Other publications[3,7] have looked at each as they impact (in total) on fossil fuel reserves, regarding nuclear fission as a means of stretching those supplies. The nuclear station input may be regarded as the heat generated so that waste heat is accounted for as a loss. Other conventions are possible; a comparison as made by Rombough and Koen is not necessarily "wrong," but it is important to recognize the limitations and implications of different methods, and make assumptions explicit.

This has also led to an inconsistent treatment of electrical inputs to the nuclear system. For the fuel cycle, input is regarded as the direct electrical input Btu, with indirect energy (associated with the coal-fired generation system) added on. No account is taken of the primary energy equivalent; i.e., of the conversion losses incurred when that electricity is generated. However, where Herendeen's input/output derived ratios are used, for capital inputs to the reactor, the energy associated with electrical inputs is regarded as the total (primary) energy required to produce that electricity, based on the generation mix at the time of data collection with certain assumptions made about the input equivalents of hydro and nuclear. That is, the efficiency in converting Btu of coal (or other source) to Btu of electricity is accounted for using the input-output methodology.

Implicit in the discussion of capacity factors and declining ore grades, is the lack of consideration of time. Although the energy inputs and outputs of the hypothetical nuclear power plant and the hypothetical coal-fired plant were found to be roughly comparable, there is no indication given by Rombough and Koen of the completely different time profile of inputs and outputs of energy in the two cases. The timing of inputs and outputs becomes important when it is realized that reactors are normally not built in isolation but in the context of a generally rapid expansion of nuclear capacity over time. The majority of energy inputs to nuclear power production must be made before the plant becomes operational. Although energy ratios for individual reactors may be very high, timing of inputs and rates of expansion for programs as a whole may be critical.[3,4]

Rombough and Koen's analysis would be far more useful if all conventions, assumptions, and limitations were explicitly stated. Many problems are still encountered in energy analysis and have yet to be overcome; however, an acknowledgement of the shortcomings and limitations would enable a better evaluation of their work alongside others.

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August 13, 1975

REFERENCES

1. C. T. ROMBOUGH and B. KOEN, "Total Energy Investment in Nuclear Power Plants," *Nucl. Technol.*, **26**, 5 (1975).

2. D. C. COMEY, "Will Idle Capacity Kill Nuclear Power," *Bull. At. Sci.*, pp. 23-28 (Nov. 1974).

3. P. F. CHAPMAN and N. D. MORTIMER, *Energy Inputs and Outputs for Nuclear Power Stations*, Research Report ERG 005, Energy Research Group, Open University, Milton Keynes, England (1974).

4. J. PRICE, *Dynamic Energy Analysis and Nuclear Power*, Friends of the Earth Ltd. for Earth Resources Research Ltd., London (1974).

5. N. VOUSDEN, "Basic Theoretical Issues of Resource Depletion," *J. Economic Theory*, **6**, 126 (1973).

6. A. Y. KNEESE, R. U. AYRES, and R. C. d'ARGE, *Economics and the Environment: A Materials Balance Approach*, The Johns Hopkins Press for Resources for the Future, Inc., Baltimore (1970).

7. P. F. CHAPMAN, *The Energy Costs of Delivered Energy; U.K. 1968*, Research Report ERG 003, Energy Research Group, Open University, Milton Keynes, England (1973).

8. R. A. HERENDEEN, "The Energy Cost of Goods and Services," ORNL-NSF-EP-58, Oak Ridge National Laboratory (1973).