Breeder Economics*

The authors of the note (*1*) on "Breeding Potential of Thermal Reactors" are to be complimented for clarification of important questions concerning U. S. uranium reserves. The great difference in reserves of high-grade uranium ores (at \$8–\$10 per pound of U_3O_8) and low-grade ores (at \$30–\$60 per pound) makes it clear that price tags must be included in any discussion of nuclear fuel reserves.

We appreciate the information added by Kaufmann and Jordan to our statement concerning the burnup of low-cost U^{235} (*2*). Nevertheless, the basic contention that a large scale nuclear power industry can not be based on low utilization of high-grade uranium ores remains unchanged. The calculations of Kaufmann and Jordan show that reserves of these ores under uranium recycle (at 0.5% fuel utilization) would last 5.3 to 16.7 years in a nuclear plant of sufficient size to match present U. S. electrical power demands. The authors also consider a projected growth of nuclear electrical power which would pass the present U. S. electrical power load in 1985. With plutonium recycle and an average conversion ratio of 2/3 (or about 2% fuel utilization) their calculations indicate that our high-grade ore reserves would last 8–24 additional years. One must conclude that, without breeders, the U. S. reserves of \$10 per pound uranium oxide are insufficient to sustain the anticipated nuclear electrical load for a significant period of time.

To obtain an assured nuclear energy supply to last several decades it is then necessary to utilize the larger reserves of low-grade uranium ores at \$30–\$60 per pound. As pointed out by Kaufmann and Jordan, these reserves may be considered "economically recoverable" when competitive nuclear power plants based on plutonium recycle are developed. However, the energy available from these ores is only $9Q$ ($1Q = 10^{18}$ Btu) at a conversion ratio of $\frac{2}{3}$ and hence does not represent a "significant extension" over the estimated $7Q$ energy content of economically recoverable fossil fuel reserves (*3*). Only in a breeder economy do these low-grade ores represent a real extension of U. S. energy reserves.

According to the projections of Kaufmann and Jordan, nuclear electrical power would reach present day levels in 2.5 decades, would carry half the expected U. S. electrical load in 4 decades and, at a conversion ratio of $\frac{2}{3}$, would exhaust U. S. reserves of \$30–\$60 per pound uranium in 9–10.5 decades. One can still "burn the rocks" and thus tap a virtually inexhaustible source of nuclear energy but, as Dr. Weinberg points out (*4*), the fuel costs of perhaps \$1–\$3 per gram (\$450–\$1350 per pound) of uranium or thorium become prohibitively high for all but breeder reactors.

Of course, the exact decade when we shall exhaust our "economically recoverable" fossil fuels or require a complete breeder economy is open to debate. It may be questioned whether predictions of U. S. power growth over a period of several decades can be "realistic," and future power demands may be underestimated. On the other hand, one can not expect a more rapid growth of nuclear electrical power than that projected by Kaufmann and Jordan for the next few decades because conventional power costs are still low. The investment in these projected nuclear power plants would amount to 20 billion dollars over the next 25 years and 80 billion dollars by the year 2000 (at \$250 per installed Kwe). However when nuclear power becomes the prime electrical energy source in (say) 4 decades, the low fuel utilization power reactor will already be obsolescent and a well-advanced breeder technology will be needed.

The need for breeders is too important for their development to continue to suffer from alternate accelerations and decelerations. A sustained program to improve the technology of breeders may be expensive and may not lead immediately to economically competitive power plants but it represents the only foreseeable way to insure economic power for the future energy needs of the United States.

The reserves of \$30–\$60 per pound uranium should be more than sufficient to start a breeder economy. Using Kaufmann and Jordan's estimates, the U^{235} reserves are sufficient to start a plant of 2.2×10^6 Mwe capacity or 24 times present capacity at a specific power as low as 0.1 Mw/kg, a goal easily met by present day thermal reactors and which is expected to be met in future fast reactors.

In summary, our points are as follows:

1. U. S. reserves of \$10 per pound uranium are sufficient to develop a large scale commercial power industry, but are insufficient to sustain it in the absence of a breeder economy.
2. The U. S. reserves of \$30–\$60 per pound uranium do not represent a significant extension of present U. S. energy reserves in the absence of a breeder economy.
3. The depletion of both economically recoverable fossil fuels and \$30–\$60 per pound uranium at low fuel utilization is expected after a period of several decades. During this period a breeder economy based on uranium and thorium ores in this price range must be established to prevent an excessive rise in fuel costs.
4. The importance of breeders to the U. S. economy is too great for their development to be postponed or to proceed in fits and starts. At present it is not yet clear whether a choice can or should be made between fast, intermediate, or thermal breeders, and between solid or fluid fuel breeders. A long breeder development program is needed to resolve these questions. A sense of urgency is necessary if a substantial breeder economy is to be established during the next 2–3 decades to help meet our mounting power needs and shrinking fuel reserves.

REFERENCES

1. J. F. Kaufmann and E. D. Jordan, *Nuclear Sci. and Eng.* **8,** 85 (1960).

2. J. Chernick and S. O. Moore, *Nuclear Sci. and Eng.* **6,** 537 (1959).

3. P. C. Putnam, "Energy in the Future," Chapter 10. Van Nostrand, Princeton, New Jersey, 1953.

4. A. M. Weinberg and H. G. Macpherson, Burning the rocks. Proc. Conf. on Physics of Breeding, ANL-6122 (1959).

Jack Chernick

Brookhaven National Laboratory,
Upton, Long Island, New York
Received August 1, 1960

* Research performed under the auspices of the U. S. Atomic Energy Commission.