possible that they are involved with the replication of phage RNA and carry no genetic message. To solve this problem, it would be of great interest to decipher all 3300 nucleotides in one phage RNA molecule. As all the necessary techniques are available, it is probably only a matter of time before this step in the control of gene expression is understood.

—GERALD L. WICK

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Power Generation: The Next 30 Years

For the past 3 decades the consumption of power in the United States has doubled every 10 years, and a number of people believe that this doubling rate is likely to continue to the end of the century. If this power is generated with existing technology, completely unacceptable levels of pollution will result.

At a symposium on "Power Generation and Environmental Change" held as part of the AAAS meeting in Boston, 16 speakers addressed themselves to the pollution problems associated with power production. Since the increased population accounts for only 20 percent of the increased power consumption, several members of the audience asked about the possibility of cutting down per capita power consumption as a solution to pollution problems. Although some of the speakers thought that this would be desirable, it was generally agreed that our society would demand the power, that it would be produced, and that changes in the technology of power production and waste disposal would be made in attempts to control pollution.

Even if nuclear reactor development proceeds rapidly, coal combustion will still account for almost half of the power produced at the end of the century. Thus, all the problems now associated with coal—including the difficult problem of controlling sulfur emission—will remain.

Most of the panelists agreed that it is easier to control pollution from nuclear reactors than from coal furnaces. Of the radioactive materials produced in nuclear reactors it now appears that most of them can be handled as solid wastes by economically acceptable techniques. The most difficult problems remaining are the development of methods for capturing krypton-85, which is now released to the atmosphere and contributes to the general background radiation, and tritium, which is part of the effluent and may be incorporated into biological systems.

Typical of the estimates for power consumption presented at the AAAS symposium are a set giving 1.5×10^{12} kilowatt-hours for 1970, 2.7×10^{12} for 1980, and 8.0×10^{12} for the end of the century. The trillion tons of coal in known, economically recoverable, reserves in the United States will last well past the end of the century, but recently passed legislation and other, expected legislation setting limits on the sulfur content of coal cannot be met with the existing supply of low-sulfur coal. Wallace Behnke, of Commonwealth Edison Company, said that short-term plans are to use more natural gas (which is the least plentiful of all fossil fuels) and foreign oil and liquid gas. When these low-sulfur fuels are exhausted, sulfur control will depend on the development of new methods of burning domestic coals.

The rate at which uranium reserves are used will depend on progress in the breeder reactor program and on our willingness to use expensive (hard to recover) deposits.

The fuel rods in the light water reactors now in use contain uranium-238 and small amounts of uranium-235 and plutonium-239, but only the last two isotopes are utilized as fuel. Uranium-238 can be used as fuel if it is converted to plutonium-239 by the capture of a fast neutron, but the fast neutrons in light water reactors are slowed down by the water coolant, and significant amounts of plutonium-239 are not produced. In the most promising types of breeder reactors, liquid sodium or fused fluoride salt coolants would be used and the concentration of fast neutrons should be high enough so that more fuel is produced than consumed.

The Atomic Energy Commission estimates that full-scale commercial use of breeder reactors will be achieved by the mid-1980's. Several observers in the coal industry and in academic and consulting positions believe that this is a very optimistic estimate, but few doubt that most of the country's nuclear power will eventually be generated by breeder reactors.

The time required for development of breeder reactors is important because they require fuels with some uranium-235, and the supply of inexpensive ores containing this isotope is limited. If reactor development proceeds as the AEC expects, the inexpensive reserves of uranium (less than $10 per pound of U_3O_8) will be used up in the mid-1980's—the same time that the AEC estimates breeder reactors will come into use. Medium-priced fuel (up to $30 per pound of U_3O_8) will be used up between 1990 and 2000, the rapid development of breeder reactors delaying the time by a few years. With breeder reactors the use of new reserves would level off around the turn of the century, after more than 1 million tons of U_3O_8 had been consumed. Without breeder reactors we would begin using up the 10 million tons of known reserves a few decades after the year 2000. The often-heard criticism that the AEC is pushing the deployment of the current generation of light water reactors too fast is based on the fear that these inefficient devices will deplete the supplies of inexpensive and medium-priced uranium.

Research for Pollution Abatement

All large coal-burning power plants in the United States use the pulverized fuel technique in which powdered coal is blown into furnaces with very large volumes. This method produces much particulate matter and leaves the waste gases in an oxidized state in a large volume of air.

The particulate matter can be collected with electrostatic precipitators. These utilize well-established technology, but they are usually larger than the furnace and are expensive to install. For example, the precipitator for the 1000-megawatt plant at Ravenswood, New York, cost $10 million.

The search for an economical method of collecting the sulfur from pulverized-fuel combustion has been going on for 30 years, but there are still no efficient devices for collecting sulfur on any large power plants now in operation. Some observers believe that with either economic incentives or laws setting lower limits on sulfur emission the power companies would have effective sulfur controlling devices developed within a few years. Others believe that there are difficult technological problems to overcome and that there is no technique on the horizon that seems to have the potential for rapid development.

At the power generation symposium Arthur Squires of the City College of New York presented a convincing case for a bolder approach to the problem. Noting that power production by coal was expected to be the major source of energy for at least the rest of the century and that sulfur emission is perhaps the major pollutant from coal combustion, he argued that major research efforts on new methods of combustion are entirely justified. As long as the sulfur is spread through a large volume of air and is in the form of sulfur dioxide—conditions inherent with pulverized-fuel combustion—the search for methods to remove it are likely to fail. Squires noted, however, that as early as 1922 a method of pulsing air and steam to burn coal (the fluidized-bed technique) had been developed in Germany. In the mid-1950's Albert Godel in France modified the method so that it was applicable to the large furnaces required for modern power production. The British are working on fluidized-bed techniques at pressures up to 15 atmospheres. The first fluidized-bed generator to be built in the United States will be a 275-megawatt plant constructed in the Wilkes-Barre–Scranton area of Pennsylvania by the UGI Corporation.

Squires said that it would be possible to combine several features of the different fluidized-bed burners now developed in such a way that the sulfur would be released as hydrogen sulfide in a small volume of air. This would require the development of techniques for extracting the sulfur under pressure, but Squires believes that this difficulty would be outweighed by the advantage of having the sulfur in its reduced form in the much smaller volume.

Although the main lines of development for fluidized-bed combustion and the sulfur-extraction techniques are known, much research needs to be done in order to have the techniques developed in time to make significant reductions in sulfur pollution within the next few decades. The National Air Pollution Control Administration plans to spend over $1 million on fluidized-bed combustion techniques in the next year, but Squires believes that many times this amount is needed and admits that the prospects of the necessary research being done are slim.

Nuclear Pollution

At the AAAS symposium Floyd Culler of Oak Ridge National Laboratory described plans to deal with the gaseous, liquid, and solid wastes produced by reactors. The troublesome gases are mostly radioactive isotopes of the noble gases. The liquid contains tritium and corrosion products that become radioactive when they circulate through the reactor. Most of the solid waste consists of spent fuel rods. Relatively simple techniques could be used to precipitate most of the radioactive waste in the effluent, and it could be added to the solid waste. Present plans call for the solid wastes to be stored for 150 days at the reactor site where radioactivity will be reduced by a factor of 30. The solids are then shipped to fuel reprocessing plants (which handle solids from about 50 reactors) where they are treated and stored for 10 years before being shipped to a repository. The AEC estimates that, by the end of the century, 800,000 cubic feet of solid waste will require 700 acres of abandoned salt mines for storage.

Krypton-85 is released to the atmosphere at both the reactor site and the reprocessing plant. The methods required to trap krypton (such as cryogenic cooling) are not simple, but the basic technology is known. The main problems are to determine acceptable levels of krypton addition and to have the technology for containing it available when this is necessary.

Tritium is produced from the lithium and boron in the primary coolant and combines with oxygen to form water. At the reactor site it becomes part of the effluent, and in the reprocessing plants it is released to the atmosphere as water vapor. In both cases it is extremely difficult to remove, and the AEC is currently considering plans to store some 200,000 gallons of tritium-bearing water each year in deep-well injection facilities. As part of a water molecule, tritium could become incorporated into biological systems and the radiation produced by its decay would be especially damaging. As with krypton, the main problem is to determine when the tritium must be stored rather than released to the environment.

Heat Balance

All current power plants produce waste heat as more than 50 percent of their total power production, and all fossil fuel plants potentially add to the earth's heat balance by producing carbon dioxide that absorbs energy reradiated from the earth after being received from the sun.

The greenhouse effect of carbon dioxide has long been known, but effects resulting from man's production of the gas have not been established. Theoretical calculations presented by Gordon MacDonald of the University of California, Santa Barbara, show that a 10 percent increase in the total carbon dioxide content would cause an increase of 0.2°C in the average temperature; doubling the content would produce an increase of 2.5°C. At the present time the total carbon dioxide content is being increased about 0.06 percent per year by the combustion of fossil fuels, but during the past 25 years—when the human addition of carbon dioxide has been most rapid—the average temperature has decreased 0.2°C. (Other climatic changes not reflected in average temperature could have occurred.)

The indirect effect of carbon dioxide addition is reinforced by the direct addition of heat from power plants. Current steam boilers lose a little more than 60 percent of their energy to the environment as heat. Gas turbine boilers with efficiencies of about 50 percent are possible within the next decade. Light water reactors now in use are only about 30 percent efficient. Very little of their waste heat can be added to the atmosphere, so these facilities require large volumes of water. Breeder reactors are expected to be about 40 percent efficient. There are no technological innovations in sight that will be able to reduce heat losses much more than gas turbines and breeder reactors.

It is estimated that by 1980 one-sixth of the freshwater runoff in the United States will be used to cool power plants and that by the end of the century the figure will have increased to one-third. Because of the large spring runoff, greater fractions of the flowing water are used for most of the year. For example, in 1980 one-half of the water will be needed for three-fourths of the year.

Until the end of the century the decisions about heat release will be based on how much change we are willing to accept. But, as with carbon dioxide, we need to learn enough to find out how much can be added without permanently changing our environment.

—Robert W. Holcomb