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Man against His Environment: the Next Hundred Years

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There is a general consensus of opinion that the world population, possibly a million or so in 10,000 or 12,000 B.C., was about 300 million at the dawn of the Christian era. In the next 1650 years it doubled, and from its new base of 600 million it quadrupled to about 2400 million in the ensuing 300 years. Because of the acceleration in population growth revealed by the data of the past few hundred years, it is now evident that a mere 100 or 125 years will be required for the next quadrupling of the population. The forces that are in operation are so titanic and inexorable that one can entertain but the faintest hope of checking the growth rate of the human population within a century. Perhaps it need not be checked; this is the problem we shall explore. But be that as it may, to judge from the trends of the past 25 years, a world population of 9000 million and a United States population of 600 million by the year 2050 are almost inevitable.

These estimates are appreciably greater than those of Putnam (*1*) and Harrison Brown (*2*): six to eight billion for the world population and 375 million (*1*) for the United States. The former is projected from the estimates of world population made by Willcox (*3*) and by Carr-Saunders (*4*). In both cases, assumptions are introduced that are incompatible with trends of the past 20 years. Harrison Brown assumes that "(i) the population of Europe (excluding Eastern Europe) and North America will cease to increase appreciably after another quarter-century. (ii) The rates of population increase of Japan, Eastern Europe, and Oceania will decrease during the next 25 years to present Western levels. In an additional 25 years, the population will become stabilized. . . ." It is also conceded that these assumptions "are little better than guesses." Putnam's estimate of 375 million for the population of the United States in 2050 results from "an arbitrarily assumed decline in the growth rate from 17 [persons per thousand of population per year] in 1953 to 9 in A.D. 2000, and nil in A.D. 2050."

While these assumptions may appear to be plausible, it is not acceptable to ignore the fact that death rates throughout the world are much more likely to go down than to go up and should indeed tend to stabilize around the present rate of nine per 1000 (for the white population of the United States) or even fall somewhat lower. The net rate of population increase in the United States, influenced slightly by immigration and emigration, fell from around 3 percent per year in the first 70 years of the Republic to 1.0 or 1.2 percent in the late 1920's and to a minimum of 0.59 percent in 1932–33. Since then it has increased steadily to a 1950–51 rate of 1.76 percent. Our present rate of population increase is greater than that of India and even higher than the world average (*5*). This phenomenon in the United States has been paralleled in recent years by the gross birth rates of 14 countries, which fell to a minimum of 1.7 percent in the period 1933–37 and have been rising steadily ever since (2.3 percent in 1947).

As an assumption, fully as plausible as those advanced by Harrison Brown and Putnam—especially if we are concerned with the magnitude of the hazards against which man must prepare himself—a world rate of population increase of 1.33 percent per year through the next century is proposed. The same rate of population increase for the United States is postulated. This would give, for the United States in 1975, a population of 217 million, which agrees with projections made by the Bureau of the Census and with estimates reported by Wooten and Anderson (*6*).

Population Growth

The growth of our species closely parallels that of a culture of microorganisms, with a long latent period followed by a rapidly ascending growth phase. In 100,000 years or more our species increased its numbers to only 600 million, but in the last 300 years our numbers burst upward to 2400 million. If the analogy with a bacterial population were to be carried further, we might expect that the present rapidly mounting growth phase would eventually slow down and that there would emerge another period of latency, in which, with a high population density, an equilibrium would be struck between births and deaths; the period of rapid population growth would have ended. The facts that are now available to the demographer are quite insufficient for estimating this hypothetical equilibrium level of population. It would be absurd to attempt any such calculation (*7*). But, on the contrary, it is essential that we look forward 100 years, largely to budget for the future, and venture an estimate about whether the environment can be so changed or the requirements of our species so modified as to permit the earth to sustain a population burden of 9000 million.

Let us first be sure of our base lines—of the things that are relatively immutable.

Climate. The earth's climate has been fairly constant for the last 1000 million years, and there is no reason to expect any appreciable change during the next million years (*8*), let alone a hundred years. This is of considerable importance in the raising of food, since temperature, rainfall, and the amount of solar energy incident upon the earth are among the principal determinants (*9*).

Land areas. The earth is of finite size,

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and the land areas will remain relatively constant for many millennia.

Biosphere. Man and all the living things on which he depends live only in the very thin interface between the heavens and the earth. Man will not be able to give himself more elbow room by vast efforts at burrowing downwards or by fanciful migrations into space. For we are talking about a *lebensraum* problem affecting at least 40 million newcomers a year.

Food requirements. Although man has been tending toward a more sedentary form of life, there is no reason for believing that the food requirement of the individual adult can be reduced for prolonged periods below 2000 Calories per day.

Hereditary factors. Even if it were feasible to apply to man the skills in breeding that are applied to plants and domestic animals, there is little likelihood that even in thousands of years one could so alter the species as to enhance its chances of survival against the pressures that threaten to develop in the next few centuries.

Feeding 9000 Million People

Clearly, the most pertinent question is whether or not the world of 2050 will be able to raise enough food to support a population of 9000 million. The answer appears to be that it will be able to do so in a sort of way, although the present inequalities in distribution will be accentuated. The land area of the earth is about 36 billion acres, of which less than one-tenth, or 2 to 3 billion acres, is under cultivation. To this may be added 6 billion acres of pasture land, which, because of unfavorable climate, poor accessibility, or low fertility, would be marginal if partial conversion to agriculture were contemplated. Finally, we have another 1 to 1.5 billion acres of marginal land in the north and in the tropics which could be brought into cultivation only at tremendous expense and with great labor. Vast sums in capital investment would be required to maintain the stability of such soils, to prevent erosion, and to provide irrigation, or drainage, and fertilizers.

Nonetheless, it appears from the calculations made by Salter (*10*) that existing techniques would permit a doubling of world food production (from the 1946 level) as an attainable goal by the exploitation of 1.3 billion acres of this marginal land. In looking ahead still further, above all to the stated objective of feeding a quadrupled population, it seems probable that more of the pasture lands would have to be used—in some instances, at very great cost—to raise cereal grains and other plants for human consumption (*11*).

One of the basic rules in human nutrition is that, in an ideal diet, one-third to one-half of the protein intake shall be derived from animal sources. The peculiar merit of animal proteins, in general, is that they contain certain indispensable ingredients—half a dozen or so amino acids—which are usually not present in adequate amounts in seed proteins. All of these can now be synthesized in the laboratory and, indeed, the manufacture of amino acids is developing into a sizable industry. One need not be much of a prophet to predict with assurance that the day will come when the use of domestic animals for meat will be reduced and when the fortification of foodstuffs of vegetable origin with factory-made amino acids will correspondingly increase. Alternatively, we may learn how to extract the very nutritious proteins of leaves on a sufficiently vast scale to use these effectively as food supplements. The necessity of some such change in nutritional practice becomes evident when we realize that the world population of cattle, sheep, poultry, and swine consumes about three times the food calories consumed by man. Only a small part of this is food refuse, unfit for human consumption. Much of it is grain and plant material deliberately cultivated for the feeding of domestic animals, and much of it is derived from pasture lands which will eventually have to be brought into agriculture.

Over 60 percent of the world's population (most of Asia, Egypt, all of Central America, and some parts of South America) consumes, on the average, less than 2200 Calories per capita per day. And such an average is deceptive, for it conceals the fact that many people in the countries concerned receive less than 2200 Calories per day. But is it not true that food production has been increasing substantially the world over? Yes, even in Egypt. But population has increased even more rapidly. The director general of the United Nations Food and Agriculture Organization was forced to report, in 1951, that even though the world's production of food had increased by 9 percent since 1934–38, the population had increased by 12 percent. In consequence, available Calories were reduced from 2380 to 2260 per capita per day, and hunger and food shortages increased (*12*).

To feed 9000 million people in the year 2050, even at minimum levels, it is reasonably certain that vast sums will have to be expended in land reclamation, in the prevention of further erosion, in the manufacture of fertilizers, in the husbanding of nitrogenous and phosphorus-containing wastes, and in irrigation and water conservation. Fisheries will be extended into the southern waters; at present, 98 percent of the world's fish catch is from the Northern Hemisphere (*2*). Domestic animals, whether used for food or for work, will be displaced—the former by the synthetic products of the food industry, and the latter by the machine. The harvesting and cropping of food from the oceans and from the fresh waters of the earth will be carried out much more efficiently, and the cultivation of bacteria, yeasts, and photosynthetic algae for human food will be further developed where regional conditions are appropriate; sunlight and carbon dioxide are needed for cultivation of the latter, and rich carbohydrate wastes are needed for the former.

Natural and Synthetic Fibers

Not all the plants raised by men are for food. Some are raised to provide him with the fibers needed for fuel, clothing, housing, paper, packaging, and so on. Trees are the principal source of plant fibers, with a present world wood consumption of about 1000 pounds per year per inhabitant (*2*). The original 15 billion acres of forest land have been reduced by man to 10 billion acres, of which 6.5 billion acres lend themselves to reforestation and sustained-yield management (*2*). Next to wood fiber in importance comes cotton, and then jute. The former accounts for nearly 60 percent of the world's fiber production, exclusive of wood. However, only about 5 percent of the world's good cropland is used to raise such fibers, while 30 to 40 percent of the world's pasture land is used to raise the sheep and goats which provide us with animal fibers.

Insofar as this country is concerned, it has been calculated (*13*) that the production of natural fibers, expressed as a percentage of total fiber production, will decrease sharply. By 1975 natural fibers will constitute little more than 50 percent of the total fiber production in this country; synthetic fibers will make up the balance. In 1930, only 4 percent of our total fibers were synthetic. The total consumption of forest products, for all purposes, in the United States in 1975 will be not more than 10 or 15 percent greater than that of 1952 (*13*). This is a safe, short-term forecast, but from other estimates it seems reasonably certain that our forest products and natural fibers will be adequate for our needs through the next century. This prediction is necessarily based on the assumption that reforestation practices will continue, that inroads upon our forest lands will be negligible, and that the synthetic fiber industry will expand into certain other countries as industrialization proceeds. A suggestion of things to come is to be found in the announcement that papers for specialized purposes can now be made from nylon and related synthetic fibers (*14*), though, for the moment, at the prohibitive price of $1 to $2 per pound (*15*).

Energy Requirements

In adapting to his environment, man has been making steadily increasing demands upon the energy-yielding substances and processes about him. His present requirements (exclusive of energy derived from food) approximate the energy equivalent of 10 tons of coal per capita per year (in the United States). In the nonindustrialized countries, the requirement is obviously much less. Up until quite recent years, man derived much of his energy from the burning of wood, from falling water, and from wind. While in 1800 the world production of energy from coal was negligible, it rose rapidly and, about 1880, began to be supplemented by that from petroleum and from hydroelectric sources (*16*). At the present time the U.S. consumption of energy approximates 160,000 kilocalories per person per day—an amount which is about 15 times greater than that required for a primitive agrarian existence and about 9 times the world average (*2*).

Fossil Fuels

What does the future hold in store for us insofar as nonfood energy sources are concerned? Half of the coal that has been consumed by man throughout his entire history has been burned since 1920. The reserves are still tremendous and, when supplemented by those of other fossil fuels (liquid petroleum, natural gas, oil shale, and tar), may amount to as much as 8000 billion tons. This is admittedly an optimistic figure for it pays scant attention to the economics of the problem, to the feasibility of extracting fossil fuels from fields that may be almost exhausted. The pessimists insist that our fossil-fuel reserves that are really amenable to extraction may prove to be as low as 800 billion tons (*2*).

Between 1940 and 1950 consumption of energy in the United States increased by 50 percent, and by 1960 it will certainly be 25 percent above the 1950 level (*17*). By 1975 we will be using energy at the rate of over 2 billion tons of "coal equivalent" per year, which is about that of the entire world at the present time. If we take into account the industrialization programs of eastern Europe, Asia, Africa, and South and Central America and the inevitable population increases of the next century, it becomes pretty clear that fossil fuels as sources of energy will have almost disappeared by the end of the next century—if present trends continue. We shall have consumed, in a scant 250 years, the fossil fuels that Nature required 250 million years to make.

To what extent will our reserves of energy in the form of unexploited hydroelectric power help us out? If they could all be put to use and put to use soon, and if we could exploit them on a maximum flow basis—three very large *if*'s—the power so derived might equal a coal equivalent of 4 billion tons per year. This could have a significant effect within the first few decades but would satisfy only 3 to 15 percent of the world's energy requirements a century from now.

Energy from Atomic Fission

And so we come to the atom, and none too soon. In 1898, Sir William Crooks, in his presidential address before the British Association for the Advancement of Science, predicted that exhaustion of the world's reserves of nitrates, then rapidly in progress, would spell the end of agriculture and, ultimately, of the species. But only 5 years were to pass before the means was discovered of fixing atmospheric nitrogen and of putting the new fixation processes at the service of agriculture. And so it is with the energy of the atom. At a most crucial moment in the history of man, scientific discovery has carried us into a new era, rich with tremendous possibilities for good and fraught with hazards of almost incredible magnitude. Just when the end of conventional sources of energy appears to be in sight, Nature reveals to man the vast new sources of energy hitherto locked within the atom.

Insofar as energy is concerned, there is no question but that the discoveries of the past few years have given us a new lease upon life. The exploitable reserves of uranium and thorium, the world over, have not been published in full. In our own country we have at least 180,000, and possibly 500,000, tons of uranium, expressed as U_3O_8, that may be mined at costs that should not prove to be prohibitive (*2, 18*). Even larger quantities of uranium are known to be in Canada, the Belgian Congo, and South Africa, while India and Brazil have rich deposits of thorium.

If it ever becomes feasible to extract the uranium from our low-grade shale and phosphate deposits and, perhaps ultimately, from our average granites, the new energy reserves would carry us very far into the future. Although the concentration of uranium and thorium in granite is very low, it is nonetheless such that, if these materials could be fully extracted, 1 ton of granite would yield an energy equivalent of 50 tons of coal. To consider the uranium and thorium of the United States alone, it may be calculated that 500,000 tons of these minerals, if fission could be carried to completion, would yield an amount of energy equivalent to that of 1500 billion tons of coal—an exploitable energy reserve which is fully equal to the world's fossil-fuel resources. World reserves of uranium and thorium have been estimated at 25 million and one million tons, respectively.

If the potential energy of these metals could be fully exploited by "breeder" techniques, this new reserve would equal 25 times that of the world's reserves of coal and 100 times the reserves of petroleum (*1*). The technical difficulties that have yet to be solved are, of course, enormous and involve the utilization of the plutonium-239 derived from uranium-238 and of the uranium-233 derived from thorium; the disposal or storage of radioactive wastes and residues; the maintenance of large inventories of uranium or thorium at every atomic power plant, and so on.

Despite all of this, progress is indeed rapid. It is now clear that Great Britain will be satisfying 20 to 25 percent of her total electricity requirements by atomic fission in 1965 and more than 40 percent by 1975 (*19, 20*). The nuclear reactor to be constructed in Somerset will have a net output of 500,000 kilowatts, which is more than 8 times that of the well-know reactor at Calder Hall (*20*). Belgium, France, Germany, Italy, Luxembourg, the Netherlands, and Japan have similar programs planned for the immediate future. In our own country there will be at least 1 million kilowatts of generating capacity in commercial atomic power plants by the end of 1960 (*21*). This will constitute only 0.7 percent of the electric power capacity that we shall then have available.

To look further into the future, it is possible that thermonuclear fusion processes will have developed sufficiently by 1975 or 2000 to give to the world atomic power plants that will be able to exploit the almost limitless reserves of deuterium with which we have been endowed. But this development awaits our ability to generate temperatures of 100 million degrees and to contain the ionized gases out of contact with the walls of the reactor—perhaps by magnetic means (*22*).

As a corollary to all of this it becomes evident that small reactors suitable for operation of motorcars and aeroplanes will have to be developed, impossible as this seems at the moment, or our reserves of fossil fuel may have to be conserved to provide the liquid fuel that they will need. And here they will face the competition of the fast-growing petrochemical industry, to which we turn for rubber and plastics.

Solar Energy

Much has been written about the limitless resources of the sun as a source of energy. We are reminded by Ayres and Scarlott (*23*) that in only 3 days we receive from the sun as much energy as could be obtained by burning all our reserves of fossil fuels plus all of our remaining forests. It is admittedly humiliating to realize that man has not yet found a more satisfactory means of utilizing solar energy for nonfood purposes than to plant forests and burn the trees. Space-heating by solar energy is certainly in the offing, but the development of solar engines that will produce more than 50 horsepower per acre of collecting area seems to be remote. Doubtless the time will come when we shall have to devote many square miles of sunny collecting areas to solar engines, though, at the present stage of development, even 50,000 square miles so employed would, at fantastic costs, produce only 2 to 5 percent of our probable energy requirements 100 years hence.

Reserves of Metals

Several excellent studies have been made of our resources in metals, one of the most recent being that by the President's Materials Policy Commission, a five-volume report published in 1952 (*24*). An industrial society requires vast amounts of metals. As with uranium and thorium, any calculation of the world's reserves of the various metals is intimately related to economics. Just how far is man prepared to go and able to go in the processing of ores of low yield? Will our supplies of energy be sufficient, and will effective substitutes be found for several of the metals for which the reserves are negligible?

At the present level of technology, and on the assumption that industrialization will continue to increase in countries that are now largely agrarian, it is reasonably certain that the world's exploitable reserves of bauxite (the most important aluminum ore), copper, lead, zinc, tin, manganese, nickel, chromium, cobalt, cadmium, and so on will have diminished to the vanishing point within 100 years. Metallurgy will, of course, make tremendous progress. Lower-grade ores will be exploited. Aluminum will be recovered from clay, and magnesium, in vast quantities, from the sea. Indeed, it has been pointed out that, from 100 tons of ordinary igneous rock, 8 tons of aluminum, 5 tons of iron, 0.5 ton of titanium, 180 pounds of manganese, 70 pounds of chromium, and so on, might be extracted. But all of this would be done at the expense of incalculable amounts of energy. It seems increasingly probable that the survival of the species in a highly industrialized world will depend in part upon man's ingenuity to use sea water, air, ordinary rock, clay, and sunlight as direct sources of raw materials and energy. Some of our essential foodstuffs, especially a number of indispensable amino acids, will have to be produced in factories, since there is little likelihood that man can long continue to enjoy the luxury of domestic animals. It is also reasonably certain that our society will become so complex, because of the evolving pattern in industry, the pressures of high population densities, and the inevitable increases in controls of all sorts designed to husband our diminishing resources and to keep us at peace with our neighbors, that governments will become more and more pervasive, and more and more domineering; the precious freedoms of the individual will diminish.

"Population Bomb"

Will it be worth while for our children and our grandchildren to struggle against such terrific odds and against so grim a future? Indeed, the struggle is worth while, but it is more and more necessary that we become fully aware of the forces with which we must wrestle, and every reasonable proposal that allegedly offers hope of improving our plight must be examined on its merits. The crux of the problem is explosive population growth; we are caught in the fast-mounting growth phase of our species. Is it possible for man "to call the shots," to fix that optimum level at which the world's population should become constant, to determine the equilibrium at which birth rates and death rates are equal, and to maintain the balance so determined with the precision that would be required? As has been so well stated by Robert Cook (*25*), "the population bomb is as great a threat to mankind as the nuclear bomb. Fortunately its fuse is longer."

We must, of course, realize more clearly than we do the dire consequences of a modern war. War, it has been alleged, in any primitive agrarian or food-collecting economy served to kill off excess numbers, to reduce population pressures, and to redistribute more equitably the food supplies and essential resources. But in a highly industrialized society, into which much of the world is moving, war can no longer be waged without catastrophic consequences. The 100 million who might be lost in another world war (*26*) represent only 2.5 years' increment to the world's population, but the attendant disruption of industry would be so complete that recovery would be improbable. The peoples of our industrialized nations are now so dependent upon industry for food and the means of transporting food, for the chemicals required in the prevention and treatment of disease, for their clothing, and so on, that a serious decrease in industrial output would be attended by disease, a sharp increase in the death rate, and reversion of the survivors to a primitive agrarian economy.

Part of the answer to the population problem is to be found in the maintenance of a very delicate balance between industry and agriculture and by a world-wide reduction in the birth rate. Science is in the paradoxical position of having given to man the means of reducing death rates and the techniques necessary for lowering birth rates but of distributing these bounties to a world that is eager to receive the former and is hostile toward the latter.

In instance after instance, the conquest of disease has served only to aggravate the major problem. In Ceylon, DDT was introduced in 1946 in a heroic effort to eliminate the *Anopheles* mosquito, the carrier of malaria. The experiment succeeded; the death rate fell from 20 to 13 in 2 years, the birth rate remained high, food production remained at the old level, and hunger and starvation increased in severity. In British Guiana infant mortality was reduced in 2 years from 350 per 1000 of population to 67. The population of the colony is now doubling every 7 years (*1*). It would be easy to show that the rapid introduction of modern sanitation practices in Egypt, India, Mexico, and Pakistan, for example, with the possible elimination of typhoid fever, infectious dysentery, and enteritis, would reduce the death rate very appreciably and, for a time, would have disastrous results on the feeding of the people; starvation and famine could attain epidemic proportions. Increasing birth rates are as serious as decreasing death rates in aggravating the population problem. I shall not attempt to explore the factors that alter birth rates; it is sufficient to mention that the causes are admittedly complex. Higher birth rates appear to be associated in part with an improvement in economic status and with the encouragement given by government, in subsidies and tax relief, to the bearing of children.

Population Control

Many remedies for the population problem are proposed. No one person can lay claim to sufficient knowledge to define a pattern of social policy that would prove effective and acceptable in achieving population control in a world as complex as ours has become. But we would be seriously remiss if we did not remind ourselves of some of the remedies that hold forth an element of promise. Abortion, at the request of the prospective mother, should not only be permitted but, in some instances, encouraged. Education in the practice of contraception should be increased and, in some regions, clinics for the teaching of contraception should be encouraged. Research on this important subject should be fostered, especially in the hope that an effective contraceptive "pill" could be developed. Governments should give serious thought to the advisability of decreasing the subsidies, family allowances, and direct benefits extended to the parents of children and the indirect relief extended through tax reductions. Possibly parents should enjoy a tax exemption of $600 for every child they do *not* have instead of a $600 reduction in taxable income for every child they do have.

It is well to recognize that research aimed at the conquest of disease and at reduction of death rates will and must continue at a high level. The desire to alleviate suffering and to save life is an expression of one of the highest spiritual values in man. It should also come to be recognized that the elimination of hunger and starvation and the improvement of the nutritional status of the poor are equally desirable objectives. But there is no hope of attaining these goals without population control. I would like to believe that the tremendous forces of organized religion and of popular education will, in the days of our children and our grandchildren, overcome the superstition, the ignorance, the apathy, and the psychological hindrances that now stand in the way of population control. I would like to believe that governments, frustrated though they may be in attempts to solve the relatively minor problem of disarmament, will be able to work in concert on the even greater, but related, problem of sharing, for peaceful purposes, the material resources of the world and of developing an acceptable program of world population control.

Lewis Strauss, chairman of the Atomic Energy Commission, in discussing the question "Can man learn to live with his inventions, or must he perish because of them?" has called for an international conference to study the "serious threats to the welfare, even the life, of the human race" that are resulting from man's inventiveness in physics, chemistry, engineering, medicine, and biology (*27*). Alexander Haddow, in calling attention to the need for an international science council, has reminded us of Lord Lindsay's proposal in 1946 that a permanent international council of scientists be organized within the framework of the United Nations (*28*). I would like to believe that our own Government will make greater use of the resources of the National Academy of Sciences for advice on the scientific aspects of matters such as these. I believe—this is a quite personal opinion on government policy—that it will eventually be necessary for the countries that are advanced technologically, and that have the resources to permit them to aid other countries, to act in concert in extending such assistance. An essential prerequisite for such assistance should be clear proof that the applicant country has introduced an acceptable program of population control and will not continue to burden the rest of the world with all the troubles inherent in expanding populations. There is, in my own mind, some question, also, about whether we have any right in our own country, in the interest of attaining higher standards of living, to drain the rest of the world of many of its precious natural resources unless we initiate measures to reduce our own rate of population increase.

There are those who insist that we shall be "sitting pretty" as long as our agricultural and industrial productivity keeps ahead of our population growth. I would submit, however, as Stanley Cain puts it, that this battle between production and reproduction will never be won by production alone.

Never-Ending Struggle

Almost every previous crisis in the history of man, except those that confronted the civilizations of the Mediterranean basin, have been solved by man's inventiveness. The life-or-death problem that now confronts the species is, paradoxically enough, the culminating result of man's ingenuity in solving his material problems. The solution of today's problem demands infinite wisdom and human understanding as well as technical progress, for the adaptations we must make in the next century will not be in material things alone. We shall have to adapt emotionally and morally. Our world of ideas, our standards of right and wrong, our ethical judgments, the things of the spirit, will be subject to strange new pressures as our cities grow larger, as expanding populations draw more heavily upon us, as governmental controls reach farther and farther into even the sanctities of our lives, and as our personal freedoms diminish.

I have described the battle of man against his environment and have indicated that his days are numbered if present trends in population growth are continued. The qualification is important, for I have enough faith in the inherent wisdom of man to believe that present trends will not be allowed to continue and that we shall have a world in which the material and spiritual values of the good life can be enjoyed for many many centuries to come. In the vastnesses of these problems the physical scientists are optimists; they are keenly aware that the technological progress of the future may shade into oblivion the advances of the past. The biologists are traditionally pessimists. They know that species may come and species may go. Being a biochemist, I am necessarily an "optipessimist." As such, I can only express the faith that man, in the wisdom with which he has been endowed, will continue to triumph in the never-ending struggle to sustain the individual and the species.

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Yale Natural Radiocarbon Measurements III

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Earlier papers from our laboratory have reported measurements of natural radiocarbon made by Libby's solid-carbon method (*1, 2*) and by Suess' acetylene method (*3*). In this article, we give results obtained between July 1955 and March 1957 (*4*), mainly by the carbon dioxide method of de Vries and Barendsen (*5*), which we have had in operation since December 1955. Work with acetylene is never entirely free from danger of explosion, as we know from experience. Moreover, the yield of acetylene is less than 100 percent, so that larger samples are required and isotopic fractionation is possible. In extending the range and accuracy of radiocarbon dating by use of larger samples, we intend to take advantage of the fact that carbon dioxide can be compressed under many atmospheres without attendant risk.

Technique

A counting system including a high-pressure proportional counter and appropriately high voltages is being installed for full realization of the advantages of the carbon dioxide method. Meanwhile, we have conducted routine dating in the same counters that were previously used for acetylene. These counters were not designed for use at high pressures. Thus, when counter 1 is filled with carbon dioxide to a pressure of 137 millimeters of mercury, it shows a background of 8.8 disintegrations per minute, and counter 2 (which has no shielding inside the ring of anticoincidence counters) has a background of 10.1 disintegrations per minute; the net activity of the modern reference standard (hemlock wood laid down between A.D. 1840 and 1850) is close to 20.0 disintegrations per minute in each counter.

We have made no important changes in the system for purification of carbon dioxide that was developed by de Vries and Barendsen. Final purification, primarily for removal of radon, is accomplished by permitting the gas to react at 800°C with calcium oxide that has been prepared from ancient calcite to insure radiochemical purity. After gaseous products are pumped away at 400°C, the carbon dioxide is liberated by increasing the temperature of the carbonate to 900°C.

Corrections of several sorts have increased the stability of the background and modern counting rates, and thus the accuracy of the dates. Changes in room temperature are compensated for during filling of the counters; the purity of the filling gas is tested before and after a run by examination of the relation between over-all counting rate and voltage in the region where this relation is linear and steep; changes in barometric pressure (with which the meson component of the over-all counting rate is inversely correlated) are corrected for when necessary. Application of these various corrections may change the observed counting rate of a sample by as much as 2 percent; corrected counting rates for anthracite and for "modern" wood then prove to be extremely stable over periods of several months, with occasional fluctuations that are attributed to neutrons (associated with solar flares). We have also observed slow, systematic but unexplained changes in background counting rate, which do not affect the calculated dates because of the frequency with which calibration runs are made.

The routine practice in dating is to make duplicate 24-hour runs, one in each counter. Calibration runs are made over weekends. The net sample/net modern wood ratios for duplicate determinations normally agree within the statistical error, so that the two can be combined into a single date. Such dates are listed in Table 1; we make no distinction between dates obtained by the acetylene method and those obtained by the carbon dioxide method.

Results

Calcareous samples have been entirely avoided because of uncertainty about the modern carbon-14 assay with which they should be compared and because of the possibility of carbon exchange between lime and atmosphere or ground water. A few preliminary studies of the radiocarbon content of modern wood from Guatemala and Yucatan have confirmed the existence of the Suess effect (*6*) (decreased radioactivity since A.D. 1900, owing to admixture of "dead" carbon from combustion of coal and petroleum); they give no support to the suspicion that forest trees in the Maya area might incorporate an appreciable amount of old carbon from a limestone substratum. Further studies of the modern assay have been deferred until mass-spectrometric studies of carbon-13 can be conducted simultaneously.

Of the major projects represented by dates in Table 1, three are essentially complete. The Alaskan Little Ice Age is

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