doing the environmental assessments is that it puts on Mack the burden of proof to show that the analyses are incomplete or inaccurate.

Mack sounds as if he is prepared to do just that. The lawyer says that all he wants from NIH is an objective and fair EIS, but he doubts that he will get one because the NIH staffers preparing the statement are supporters of the research.

Despite his attempt to halt renovation of the laboratory, Mack is not worried that the physical facilities themselves are inadequate to do the containment job for which they were designed. Rather, his main concern is that human error will result in the release of some pathogen into the community where he lives. He contends that it is all right for scientists to decide to take a risk for themselves but it is not fair for them to impose the same risks on the community at large.

In contrast, both NIH and CDC officials maintain that in the long history of microbiological research, much of it with pathogens, there has been little if any documented evidence for the spread of infections acquired in the laboratory to the community. However, in the past infections have been acquired by laboratory personnel and, on occasion, by visitors. Thus, the fervor of the debate over recombinant DNA research makes it likely that a sharp watch will be kept over the operation of the new P4 facilities.—JEAN L. MARX

Carbon Dioxide and Climate: Carbon Budget Still Unbalanced

The continuing growth in consumption of fossil fuel has raised the possibility of global climatic changes induced by carbon dioxide. Accurate predictions of such changes are hampered partly because a basic understanding of the production, consumption, and storage of carbon on the earth still eludes researchers. Most investigators in the diverse fields involved agree that more CO_2 is being produced than can be reliably accounted for, but there is broad disagreement as to how much is missing. Researchers also cannot agree about where it is most likely to be found. The controversy is one aspect of the debate on the long-term reliance on coal versus energy sources producing no new CO_2 such as nuclear, solar, and biomass sources.

The amount of CO_2 in the atmosphere has been observed to increase steadily since a monitoring program was begun in 1958, but the increase is equivalent to only about 50 percent of the CO_2 known to have been produced by fossil fuel burning in the same period. Until recently, it had been widely accepted that part of the remainder entered the oceans and part was taken up by terrestrial green plants. Now, however, some biologists are maintaining that it is not likely that any of the excess CO_2 is stored in land plants, and some researchers even contend that the land is a significant source of CO_2. The obvious conclusion that all the excess CO_2 is in the oceans is, however, disputed by many oceanographers. They maintain that the ocean cannot take up CO_2 fast enough.

The importance of the debate is that the future rate of increase in atmospheric CO_2 depends upon the relative importance of the various processes supplying it as well as those removing it. While the rate of increase over the last 20 years has paralleled the increase in fossil fuel consumption, the suggestion of deforestation as a major source of CO_2 has complicated the prediction of future levels.

George Woodwell of the Marine Biological Laboratory at Woods Hole is a leading American proponent of the idea that deforestation of the land creates a CO_2 source. He has attempted to estimate the amount released during the destruction of forests over and above that taken up by the regrowth of vegetation. His calculations, as do all others, depend on limited data gathered from relatively small geographical areas for extrapolation to a global scale. These data include observed rates of clearing of tropical forests in one region of Venezuela and in two regions of Brazil. The use of assumptions about the fraction of cleared vegetation that is converted to CO_2 and the rate of regrowth of the forest allows an estimation of the net amount of CO_2 released from tropical forests each year. The tropical forests represent the largest mass of carbon in land plants. Temperate and northern forests have also experienced regrowth after extensive exploitation. Allowance for this uptake was based on reforestation data for the state of Maine. Yet another reservoir of carbon is to be found in soil organic matter which contains several times the carbon in living plants. Woodwell believes, on the basis of field data primarily from South America, that losses to the atmosphere from this source have been enhanced because of increased exposure by cultivation and deforestation.

He and a number of his colleagues estimate that an amount of carbon equivalent to probably 80 to 160 percent of the fossil fuel CO_2 is being released as the net result of deforestation. Although such calculations represent "an educated guess," Woodwell contends that "we know a great deal about forests and a good deal about succession," the progressive regrowth of cleared land.

Other investigators have developed similar if less extreme estimates following the same general reasoning. Bert Bolin of the University of Stockholm estimates that releases from the living and dead organic matter (the biota) on land equal 10 to 35 percent of the fossil fuel contribution. C. S. Wong of the Institute of Ocean Sciences, Victoria, British Columbia, sets an upper limit of about 30 percent for the biotic contribution. Woodwell believes that no lines of reasoning currently under consideration suggest that the biota is taking up more CO_2 than it releases, or in other words, that it is acting as a sink.

These tentative findings appear to exacerbate the problem of the missing CO_2. Rather than providing a storage place for approximately 20 percent of the fossil fuel CO_2, the land biota would be a significant source of CO_2. In the worst case, a storage place for three times the quantity of carbon previously considered would need to be found. Although proponents of such a source do not know where the excess CO_2 goes, they often suggest that it probably ends up in the ocean.

Oceanographers dispute the assertion that such large quantities of CO_2 could be absorbed by the ocean. They point out that the ocean as a whole is a relatively sluggish body of water. Its surface waters, which are only about 75 meters thick, are well stirred and free to exchange CO_2 with the atmosphere. But these shallow waters cannot store the necessary quantities of CO_2. The deep waters, which constitute the bulk of the oceans, circulate very slowly. This is important because the use of fossil fuels has been so concentrated in recent years that the average age of all the fossil CO_2 released to date is 28 years, a period in which only a few percent of the deep water exchanges with surface water.

The warmer suface layer is separated from the cold, deep water by a region known as the thermocline in which temperature decreases rapidly with depth. The thermocline acts as a barrier between the upper and lower waters by inhibiting mixing processes. The slow mixing, oceanographers argue, means that excess CO_2 in surface waters could not have penetrated the thermocline completely and mixed with deep water.

It would take decades to detect a change in the CO_2 content of the ocean with current techniques. But estimates of the amount of CO_2 absorbed by the ocean can be made on the basis of the dispersal of natural and bomb-produced radioisotopes in the ocean. Such data were collected as part of the extensive Geochemical Ocean Sections (GEOSECS) program (*Science*, 14 January, p. 164).

Wallace Broecker, a geochemist at Columbia University's Lamont-Doherty Geological Observatory, using the data from GEOSECS and elsewhere, has calculated the rates of exchange between the atmosphere and the different layers of the ocean. On the basis of these exchange rates, about 37 percent of recently generated fossil fuel CO_2 has entered the oceans.

The key uncertainty seems to be the rate at which CO_2-laden surface water is transported into the thermocline region. Oceanographers generally agree that the best available method to follow such movement is the use of nuclear bomb–produced tritium (hydrogen-3) which entered the surface of the ocean mainly in the early 1960's. Being radioactive, the tritium, in the form of water molecules, can be used as a marker to indicate the surface water as it penetrates the thermocline. The tritium data from GEOSECS indicate that less than one-half of the thermocline region would be penetrated by fossil fuel CO_2. These overall results are essentially identical to those calculated by H. Oeschger and his colleagues in 1975 using radiocarbon to trace the movement of carbon.

Broecker asserts that his estimate of the ocean's CO_2 capacity is not low by more than one-fifth. If correct, this would appear to shut the door on any large uptake of excess CO_2 by the ocean. Virtually all analyses of ocean circulation in relation to CO_2 uptake have led to the same general conclusion. The result has been to heighten the difficulties involved in the proposed biotic source.

This confrontation of opposing viewpoints has been punctuated by complaints of insufficient or incomplete data, and it highlights just how weak the present understanding of the global carbon cycle is. Early suggestions by Charles Keeling of the University of California, San Diego, and Lester Machta of the National Oceanic and Atmospheric Administration that the land biota must take up CO_2 went largely unchallenged by biologists. While photosynthesis (and therefore CO_2 absorption) is increased by increasing CO_2 levels under ideal laboratory conditions, the effect has not been demonstrated on a large scale in a natural environment. Recently, Edgar Lemon, a U.S. Department of Agriculture researcher associated with Cornell University, investigated the importance of factors other than CO_2 which can limit growth; he concluded that the global rate of CO_2 uptake by photosynthesis has not changed greatly under the influence of increasing CO_2 levels during the last 100 years.

Estimates Questioned

A more hotly contested question is the reliability of estimates of man's impact on the biota. A contingent of researchers views the current calculations of deforestation as a bit extreme or even premature. Jerry Olson of the Environmental Sciences Division of Oak Ridge National Laboratory feels that while deforestation may be significant, the more extreme global extrapolations will not be sustained. He suggests that further research may reveal that the opposing factors of deforestation and CO_2-enhanced photosynthesis tend to nullify each other. Frederick Smith, an ecologist at the Harvard School of Design, characterizes estimates to date as "only intuitive judgments" and points to what he believes to be large margins for error. Many agree with Lemon that there is simply insufficient reliable data to make any kind of guess.

Opinion also varies concerning the precision of ocean circulation calculations. Although the general magnitude of likely CO_2 uptake by simple dissolution in the ocean is not disputed, some oceanographers remain cautious. George Veronis, a physical oceanographer at Yale University, observes that "the amount of data available on the rate of ocean mixing is not as much as one would like. A really good measurement program has not been developed."

Gote Östlund, a geochemist at the University of Miami's Rosentiel School of Marine and Atmospheric Science, argues that, in spite of the limitations of the GEOSECS data, the conclusions drawn from them and related data are quantitative, reasonably representative of the ocean as a whole, and not subject to gross errors.

Advocates of a very large uptake by the ocean often point to poorly understood marine processes as possible unidentified CO_2 sinks. For example, it is generally acknowledged that the flows of carbon in the ocean which are under biological influence are poorly quantified, but oceanographers point out that this does not necessarily mean that marine plants are a sink for CO_2. John Ryther, a marine biologist at Woods Hole Oceanographic Institution, says, "I can't think of a good mechanism for altering those flows to accommodate much more carbon in the present situation."

One possible way of accommodating more carbon would be to increase the productivity of coastal marine plants and thus store additional carbon as plant material and organic debris. Frederick MacKenzie, a geochemist at Northwestern University, has estimated the amounts of additional nutrients that may be entering the coastal ocean as pollutants from rivers, and concludes that it is not large enough to account for more than a small portion of the missing CO_2. But some investigators speculate that the presence of this additional organic debris in the bottom sediments may retard recycling of organic matter and its eventual return to the atmosphere as CO_2 by altering the chemical environment of the sediment. Another possibility is that the rate of sediment accumulation may have increased because of man's activities on land, hastening the isolation of plant debris from the recycling process.

Still another process in the nearshore zone receiving increased attention is the possible dissolution of calcium carbonate, the solid, inorganic form of CO_2 deposited on the ocean floor by biological activity in surface waters. Absorption of fossil fuel CO_2 by surface waters makes them more acidic and thus more corrosive toward calcium carbonate. Increased dissolution of calcium carbonate, if it occurred, would increase the capacity of seawater to absorb more CO_2. This is because the dissolved carbonate ion, which is in limited supply, is a required participant in the dissolution of atmospheric CO_2 in seawater. Marine chemists generally feel that this process is too slow to be significant over the next two centuries, but Robert Garrels of Northwestern University has recently pointed out that a more soluble form of calcium carbonate also occurs naturally in the ocean and may tend to accelerate the process.

The resolution of the debate concerning the missing CO_2 will only come with the development of more reliable data, but that will not occur without close cooperation among researchers from many fields, including terrestrial biology and oceanography. Such cooperation has been largely absent. In the meantime, the best assumption would appear to be that CO_2 will continue accumulating in the atmosphere as it has in the recent past.—RICHARD A. KERR