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J.F. BLACK
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June 6, 1978

The Greenhouse Effect

Ref. No: 78PR 461

Mr. F. G. Turpin, Vice President
Exxon Research and Engineering Co.
Petroleum Staff
P. O. Box 101
Florham Park, NJ 07932

Dear Frank:

The review of the Greenhouse Effect which I presented to the Exxon Corporation Management Committee last July used only vugraphs, without a prepared text. Last month, I had the opportunity to present an updated version of this talk to PERCC. The attached text was dictated shortly afterward to satisfy requests for a written version of the talk from people who had not heard the presentation last July. Also attached is a summary.

Sincerely,

Jim

J. F. BLACK

JFB/mbh
Attachments: Summary
Text
Vugraphs

CC: Messrs. N. Alpert
W. M. Cooper, Jr.
E. E. David
E. J. Gornowski
R. L. Hirsch
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THE GREENHOUSE EFFECT

J. F. Black, Products Research Division
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SUMMARY

The earth's atmosphere presently contains about 330 ppm of CO_2. This gas does not absorb an appreciable amount of the incoming solar energy but it can absorb and return part of the infrared radiation which the earth radiates toward space. CO_2, therefore, contributes to warming the lower atmosphere by what has been called the "Greenhouse Effect."

The CO_2 content of the atmosphere has been monitored since 1957 at two locations, the Mauna Loa Observatory, Hawaii and the South Pole. These and other shorter studies show that CO_2 is increasing. If the increase is attributed to the combustion of fossil fuels, it can be calculated that the CO_2 content of the atmosphere has already been raised by about 10 to 15% and that slightly more than half of the CO_2 released by fossil fuel combustion is remaining in the atmosphere. Assuming that the percentage of the CO_2 remaining in the atmosphere will stay at 53% as fossil fuel consumption increases, one recent study predicts that in 2075 A.D., CO_2 concentration will peak at a level about twice what could be considered normal. This prediction assumes that fossil fuel consumption will grow at a rate of 2% per year until 2025 A.D. after which it will follow a symetrical decrease. This growth curve is close to that predicted by Exxon's Corporate Planning Department.

Mathematical models for predicting the climatic effect of a CO_2 increase have not progressed to the point at which all the feedback interactions which can be important to the outcome can be included. What is considered the best presently available climate model for treating the Greenhouse Effect predicts that a doubling of the CO_2 concentration in the atmosphere would produce a mean temperature increase of about 2°C to 3°C over most of the earth. The model also predicts that the temperature increase near the poles may be two to three times this value.

The CO_2 increase measured to date is not capable of producing an effect large enough to be distinguished from normal climate variations. As an example of normal variations, studies of meteorological and historical records in England indicate that the mean temperature has varied over a range of about ±0.7°C in the past 1000 years. A study of past climates suggests that if the earth does become warmer, more rainfall should result. But an increase as large as 2°C would probably also affect the distribution of the rainfall. A possible result might be a shift of both the desert and the fertile areas of the globe toward higher latitudes. Some countries would benefit but others could have their agricultural output reduced or destroyed. The picture is too unclear to predict which countries might be affected favorably or unfavorably.

It seems likely that any general temperature increase would be accentuated in the polar regions, possibly as much as two- or three-fold as mentioned above. Any large temperature increase at high latitudes would be associated with a reduction in snow cover and a melting of the floating ice-pack. Present thinking suggests that there would be little or no melting of the polar ice-caps in response to warmer temperatures on a time scale over which the Greenhouse Effect is predicted to apply.

A number of assumptions and uncertainties are involved in the predictions of the Greenhouse Effect. The first is the assumption that the observed CO_2 increase can be attributed entirely to fossil fuel combustion. At present, meteorologists have no direct evidence that the incremental CO_2 in the atmosphere comes from fossil carbon. The increase could be at least partly due to changes in the natural balance. There is considerable uncertainty regarding what controls the exchange of atmospheric CO_2 with the oceans and with carbonaceous materials on the continents.

Models which predict the climatic effects of a CO_2 increase are in a primitive stage of development. The atmosphere is a very complicated system, particularly on a global scale. In existing models, important interactions are neglected, either because they are not completely understood or because their proper mathematical treatment is too cumbersome. Substantial efforts are being expended to improve existing models. But there is no guarantee that better knowledge will lessen rather than augment the severity of the predictions.

The Greenhouse Effect has been the subject of a number of international scientific conferences during the past two years. These meetings have identified the information needed to definitely establish the source and ultimate significance of the CO_2 increase in the atmosphere. Present thinking holds that man has a time window of five to ten years before the need for hard decisions regarding changes in energy strategies might become critical. The DOE is presently seeking Congressional support for a research program which will produce the necessary information in the required time. This program is described.

THE GREENHOUSE EFFECT

By

J. F. BLACK

Transcript of a Talk
Delivered Before the PERCC Meeting
May 18, 1978

The Greenhouse Effect refers to a warming of the earth's atmosphere due to an increase in the concentration of carbon dioxide. As a background for the discussion today, the first vugraph outlines the basis for the Greenhouse Effect.

The earth receives energy in the form of both visible and ultraviolet radiation from the sun. Some of this radiation is reflected back into space, some is absorbed by the atmosphere but most is absorbed at the earth's surface. The earth in turns reemits energy in the form of infrared radiation toward space. Carbon dioxide and other atmospheric constituents absorb part of the infrared radiation. This absorbed energy warms the atmosphere. Therefore, higher carbon dioxide concentrations result in a more rapid absorption of the outgoing infrared radiation and warmer temperatures near the earth's surface. In my talk today I am planning to discuss:

I. The Source and Projected Magnitude of the CO_2 Increase in the Atmosphere

II. The Global Temperature Increase Which Can Be Expected From Higher CO_2 Concentrations

III. The Potential Problems Arising From a Global Temperature Increase

IV. Research Needed to Establish the Validity and Significance of Projected Increases of CO_2 in the Atmosphere.

My information is derived from following recent literature in this area and from talks with some of the leading research people in the field.

I. The Source and Projected Magnitude of the CO_2 Increase in the Atmosphere

Since 1958, CO_2 has been monitored at a number of remote sites which are free from local inputs (Vugraph 2). These are Point Barrow, Alaska; some Swedish aircraft flights; Mauna Loa, Hawaii; American Samoa and the South Pole. The carbon dioxide concentration has been found to be increasing rather uniformly at all locations with the South Pole measurements rather lagging those in the Northern Hemisphere.

Atmospheric scientists generally attribute this growth in CO_2 to the combustion of fossil fuel. A principal reason for this is that fossil fuel combustion is the only readily identifiable source which is (1) growing at the same rate, (2) large enough to account for the observed increases, and (3) capable of affecting the Northern Hemisphere first. If this assumption regarding the origin of carbon dioxide is true, it can be calculated that a little over 50% of the CO_2 entering the atmosphere is remaining there and the rest is being absorbed in surface sinks on the continents or in the ocean. Extrapolating backwards in time to follow the history of fossil fuel combustion, it can be estimated that since 1850 the concentration of this gas in the atmosphere has increased by about 13%. This increase amounts to about 75 billion metric tons of carbon dioxide.

It is also possible to extrapolate into the future. One of the most commonly quoted extrapolations is that of the Oak Ridge National Laboratory which was published in 1976[1]. This study produced two scenarios for the growth of fossil fuel consumption (Vugraph 3). Prior to 1973, fossil fuel use had been growing exponentially at about 4.3% per year. The scenario for most rapid growth assumed that this growth rate would continue, modified by a depletion factor which reduced the exponent in proportion to the amount of fossil fuel which remained unburned. Their second and more conservative assumption presumed that fossil fuel utilization would grow with a 2% growth rate out to 2025 A.D. followed by a symetrical decrease. This latter scenario is close to that developed independently by the Coordination and Planning Department of the Exxon Corporation.

Vugraph 4 presents the predicted atmospheric carbon dioxide levels which would result from each of these scenarios. The vertical axis in this vugraph presents the atmospheric carbon dioxide concentration relative to that which was calculated to have existed in 1850, prior to the combustion of appreciable amounts of fossil fuel. It can be seen that the scenario based upon very rapid growth predicts that by 2075 the atmospheric carbon dioxide concentration will be about 4 to 5 times that which existed prior to the industrial revolution. Moreover, at that time, the carbon dioxide concentration will still be increasing. The more conservative assumption, shown in the lower curve, predicts that carbon dioxide concentrations will level out about a century from now at a value which is about twice that in existence in 1850 and then would decline at a very slow rate.

Although carbon dioxide increase is predominantly attributed to fossil fuel combustion, most scientists agree that more research is needed to definitely establish this relationship. The possibility that the increasing carbon dioxide in the atmosphere is due to a change in the natural balance has not yet been eliminated. In fact, a look at the magnitude of the natural interchanges, as shown in Vugraph 5, shows that this possibility should be taken seriously.

The data in Vugraph 5 are taken from a Scientific Workshop on Atmospheric CO_2 sponsored by the World Meteorological Organization in December 1976. The vugraph shows the fluxes of CO_2 into and out of the atmosphere in units of billions of metric tons of carbon per year. It can be seen that fossil fuels are estimated to contribute five billion tons of carbon per year to the atmosphere and that about half of this is reabsorbed by the oceans or by the biosphere. The conclusion that fossil fuel combustion represents the sole source of incremental carbon dioxide involves assuming not only that the contributions from the biosphere and from the oceans are not changing but also that these two sources are continuing to absorb exactly the same amount as they are emitting. The World Meteorological Organization recognized the need to validate these assumptions, particularly in view of the fact that the rate of carbon dioxide increase represents less than 2% of the rate at which the atmosphere is exchanging carbon dioxide with the biosphere and the oceans.

The biologists have been claiming that deforestation and associated biogenic effects on the continents represent an important input of carbon dioxide to the atmosphere. Vugraph 6 summarizes the results from recent papers by a number of biologists on the contribution of the biosphere to the growth of CO_2 in the atmosphere relative to the contribution of fossil fuel combustion. Their estimates for this ratio are presented in the first column. In April of 1977, Adams[2] estimated that the ratio of the weight of carbon from net wood burned to the weight of carbon from fossil fuel burned in this century has been at least 0.1 and may have approached 1.0. The following month, Bolin[3] claimed that the increase in carbon dioxide due to the expansion of forestry and agriculture was at least half that due to fossil fuel combustion. In August of 1977, the National Academy of Sciences issued a report[4] which attributed the Greenhouse Effect to fossil fuel combustion and which received a considerable amount of sensational publicity. This has produced a rash of papers by the biologists to support their position. In January of this year, Woodwell[5] and a number of other authors from academic and oceanographic centers published a paper claiming that the terrestrial biomass appears to be a net source of carbon dioxide for the atmosphere which is possibly greater than that due to fossil fuel combustion. The following week, Stuiver[6] published results based upon C^{13}/C^{12} ratios which reported that the net release of carbon dioxide from the biosphere in the century prior to 1950 was twice as great as that from fossil fuel combustion. Even if it is assumed that the biospheric release stopped in 1950, the contribution of the biosphere up to the present time would still be 1.2 that from fossil fuel. The last four articles which I have quoted were all published in Science. In the present month, Wilson[7] published an article in Nature which supports the claim that deforestation has produced at least half as much carbon dioxide in the atmosphere as can be attributed to fossil fuel.

Now, you will remember that earlier in this talk it was pointed out that if the increase in carbon dioxide in the atmosphere is due to fossil fuel combustion, about 50% of the CO_2 being released remains in the atmosphere and the rest is absorbed in either the oceans or the continents. If there have been substantial releases of carbon dioxide in addition to that which can be attributed to fossil fuels, the natural sinks for carbon dioxide must be larger and more efficient than previously estimated. This would reduce the levels to which carbon dioxide has been projected to increase. This possibility is vehemently denied by the oceanographers, who claim that the oceans cannot possibly absorb much more carbon dioxide. However, it is my impression that the science of oceanography has not as yet reached a state of development which can justify such a positive claim.

The current status of scientific opinion regarding the carbon cycle is summarized in Vugraph 7. First, current scientific opinion overwhelmingly favors attributing atmospheric carbon dioxide increase to fossil fuel combustion. However, most scientists feel that more research is needed to support an unqualified conclusion. Finally, some scientists, particularly the biologists, claim that part or all of the CO_2 increase arises from the destruction of forests and other land biota.

II. <u>The Global Temperature Increase Which Can Be Expected From Higher CO_2 Concentrations</u>

Predictions on the significances of increases in atmospheric CO_2 must be based upon climate modeling. Modeling climatic effects is currently handicapped by an inability to handle all the complicated interactions which are important to predicting the climate. Some of these are shown in Vugraph 8.

One interaction which has not has yet been included with any degree of sophistication in climate models is the effect of cloudiness. Clouds can reflect incoming visible and ultraviolet radiation back into space with greater efficiency than would occur at the ground. On the other hand, at their bottom surface they absorb outgoing radiation and the cloud tops also emit infrared radiation, depending upon the temperature (that is altitude) at which the top is located. The effect of a cloud will therefore depend upon its size, its shape, and the altitude at which it is located.

Another uncertainty which has not, as yet, been handled in any great detail is the atmosphere - ocean circulation - sea surface temperature interaction. How should the heat capacity of the oceans be handled in view of the turbulence at the surface and to what depths are the oceans involved in interacting with the atmosphere? These are important questions because the entire heat content of the atmosphere is equal to the heat content of just the first three meters of the oceans. A third uncertainty in modeling is the interaction between the seasons and long-term climate trends. In present models, the changes which are predicted for increasing carbon dioxide concentrations are calculated with respect to a constant climate, that is a perpetual spring or summer season. It is quite possible that this assumption is inadequate. For example, the best accepted explanation for the on-set of the ice ages is that orbital and other changes result in the earth entering a period in which summers are cooler and winters are warmer than normal. Thus, this produces more precipitation and faster glacier growth during the winter and less melting during the summer.

Finally, a serious question has been raised as to whether climate is really predictable. This possibility was raised by Lorenz[8] in 1970. He drew an analogy to mathematical modeling. Many mathematical models of complicated phenomena are based upon a large number of non-linear equations with a variety of complex feedback interactions. If the mathematician is fortunate, when a model of this type is run on the computer, it will converge and give him a definite answer. Such a model is called transitive. On the other hand, when a complicated model is tested, it is not at all unusual to find that the solution will not converge but will oscillate back and forth without producing a stable answer. Such a model is called intransitive. There is also an intermediate condition. Occasionally, a model is found to converge initially upon a definite answer but after a short period to jump off this solution and settle down upon another one. After a second indefinite period, it will jump up and converge again upon a third solution and so on producing a number of apparent solutions in a random manner. Such a model is called almost transitive (or almost intransitive). Lorenz pointed out that the climate is a system which is the result of a large number of non-linear energy inputs between which there are many complicated feedback interactions. He therefore suggested that the climate may be a natural example of an almost transitive system which does not have a stable solution. It will settle down into an apparently stable condition but then after a random period will jump over to another apparent stability, etc.

It is not certain, however, that such a pessimistic outlook is justified and it has not stopped the development of many models of the Greenhouse Effect and other climate phenomena. The simplest of these are the one-dimensional models in which the input at the earth's surface is averaged over the globe and detailed calculations are carried out to predict vertical variations. Such models do not require much computer time and can include detailed treatment of vertical phenomena such as radiative transfer. They suffer, however, from the fact that the influence of latitudinal variations is completely ignored.

The next more complicated models are so-called zonally averaged models in which various latitude regions are treated separately in a two-dimensional manner. These take more computer time but are still short enough to permit considerable sophistication in the calculations. They still suffer, however, from an incomplete treatment of latitudinal interactions. In spite of this, many modelers feel that they are the most valuable type of model upon which to work.

The most complicated models are the so-called general circulation models which are three-dimensional in character. These take very long times to compute and the ratio of real to machine time can be as low as 10 to 1. A great deal of the computer time is spent in moving large masses of air around the globe and recalculating the snyoptic profiles every 10 to 15 minutes. Their advantage is that latitudinal effects are completely included but the sophistication with which vertical effects can be treated is limited due to the time and expense associated with running the model.

One of the best general circulation models of the Greenhouse Effect, and the one which is most frequently quoted, is that developed by Manabe and Wetherald[9]. Their predictions for the climatic effect of a doubling of CO_2 are presented in Vugraph 9. This vugraph predicts that a doubling of the atmospheric CO_2 concentration would produce a temperature rise at lower altitudes and a temperature decrease above twenty kilometers. At the surface the temperature rise would be about 2 to 3°C from the equator up to about 60° latitude, with a much greater increase predicted for the poles. The larger increase at the poles results from two effects. First, vertical mixing at the poles is reduced due to a natural decrease in the height of the inversion layer in these regions. Second, the model contains a temperature - ice and snow cover - reflectivity interaction by which increases in atmospheric temperature melt the snow and ice cover and reduce the amount of heat reflected back into space.

Simplifications incorporated in this model include fixed cloudiness, a "swamp" ocean which has zero heat capacity, and idealized treatment of the topography. The model also contains a simplified treatment of the infrared radiation transfer in the atmosphere. In a separate calculation, Manabe[10] calculated that the use of a more sophisticated treatment, developed by Rodgers and Walshaw[11], would reduce the indicated temperature increases at the surface by about 0.5°C. In the light of this and other models, it is generally accepted by climatologists that a doubling of the carbon dioxide concentration in the atmosphere would produce from 1.5°C-3.0°C warming at the earth's surface in the lower and mid-latitudes with about 2 to 3 times greater effect at the poles.

The next natural question is the significance of such a temperature rise compared to the magnitude of the natural temperature changes which have been observed to occur in the past. A comparison with respect to historical temperature changes since 1850, according to Kellogg[12], is presented in Vugraph 10. In this figure, the observed mean Northern Hemisphere temperature is plotted as the solid line. It can be seen that this has varied less than ±1°C over the last century. The extrapolations past 1977 result from the application of Manabe and Wetherald's model[9] with the assumption that the carbon dioxide levels will double by 2050 A.D. The lower dashed line in the figure represents an estimate of what the recent temperature trends would have been if the CO_2 increase had not occurred.

The significance of a temperature increase of the magnitude predicted by Manabe and Wetherald with respect to the long term record of climate is presented in Vugraph 11 which was prepared by Mitchell[13]. This figure shows that the expected temperature increase would be large even compared to the temperatures at the time of the last interglacial. As this temperature increase decayed, however, it would represent an amelioration of an expected natural cooling trend.

III. The Potential Problems Arising from a Global Temperature Increase

The implications arising from Manabe and Wetherald's predictions for the temperature effects resulting from a doubling of carbon dioxide concentrations in the atmosphere are outlined in Vugraph 12. It appears fairly certain that if the high increases they predict in the polar regions do occur, the permanent snow cover and floating sea ice will be reduced or possibly eliminated. This will have a negligible effect on sea level, however, since the snow cover does not represent an appreciable amount of water and the floating ice is already in equilibrium with the sea.

There will probably be no effect on the polar ice sheets. These are three in number. The Greenland ice sheet in the Northern Hemisphere represents an amount of water equivalent to a five meter rise in sea level. If the floating sea ice is removed, the Greenland ice cap would be surrounded by water. This might produce increased precipitation and actually result in the growth of this ice sheet.

The world's largest ice sheet is the East Antarctic sheet which contains water equivalent to a rise of 70 meters in the world's oceans. It is estimated that the temperature effects produced by doubling the atmospheric CO_2 concentration would not affect this very large glacier and that it too might increase in size.

The area on which most uncertainty exists is with respect to the West Antarctic ice sheet. The water in this glacier is equivalent to about a seven meter rise in the world's oceans. The West Antarctic ice sheet extends out over the ocean floor. Warmer oceans might result in an intrusion of the ocean waters underneath this ice sheet and a decrease in its size might occur. If this happens, an oceanic rise of some fraction of the maximum amount (7 meters) might take place.

With a warmer climate around the world, it seems fairly certain that precipitation would increase. On a global basis, this should result in a lengthening of the growing season. Growing seasons are estimated to increase about ten days for each 1°C rise in temperature.

The changing precipitation patterns, however, would benefit some areas and would harm others. It is not possible, on the basis of present information, to predict just where these effects would occur. As a first estimate, one might say that the climatic zones in the world would move northward. The effect of this on the agriculture of the U.S. and Russia is indicated in Vugraph 13.

The broadening of the equatorial regions might result in a northward migration of the desert areas in the United States. Our present corn and wheat belts would also move northward and migrate into Canada. It can be seen that Russia, which is indicated by the crossed hatched area, lies considerably farther north than does the United States. The very dark areas indicate the agricultural regions of Russia. If climatic zones migrate northward, the Russians have plenty of room to adopt to the change. Even those nations which are favored, however, would be damaged for a while since their agricultural and industrial patterns have been established on the bais of the present climate.

IV. Research Needed to Establish the Validity and Significance of Projected Increases of CO_2 in the Atmosphere

The Greenhouse Effect has been attracting a large amount of scientific attention. Some of the more important recent meetings on this subject are presented in Vugraph 14. The World Meteorological Organization held a scientific workshop on atmospheric CO_2 in Washington, DC, in December 1976. ERDA held a workshop on the Environmental Effect of CO_2 from Fossil Fuel Combustion at Miami in March of 1977. This meeting was organized by their Advisory Committee for research on the Greenhouse Effect, the Chairman of which is Dr. Alvin Weinberg. DOE's present research effort on the Greenhouse Effect is a direct result of this workshop and I will be saying more about their program later. SCOPE (Standing Committee on the Planetary Environment), a West European organization, held a workshop on the world carbon budget in March of 1977 in Hamburg, Germany. The most recent major meeting was that organized in Luxenburg, Austria, this past February by IIASA (International Institute for Applied Systems Analysis) for the World Meteorological Organization, the U.N. Committee on the Environment and SCOPE.

The conclusions from this last meeting summarize the present world scientific opinion with respect to the Greenhouse Effect. The IIASA meeting was organized into three working groups. Some of the more significant recommendations of these working groups are presented in Vugraph 15.

The working group on the carbon cycle concluded that scientific confidence in models of that cycle is considerably less than it was ten years ago. What is necessary to instill greater confidence is to provide a better understanding of the flux from the biosphere as reported by the biologists. The working group also recommended that more information be obtained on the interchange of CO_2 into the ocean and how it is transported to greater depths.

The second working group, on the climatic impact of a doubling of CO_2, reached conclusions close to those which have been summarized in the present talk. They felt that a doubling of atmospheric carbon dioxide would produce a 2-3 degree centigrade increase in temperature depending upon the influence of clouds.

The third working group was concerned with the impact of the Greenhouse Effect on energy strategies. They recommended that man can afford a 5-10 yr. time window to establish the validity and significance of the Greenhouse Effect. They said that it is premature to limit the use of fossil fuels at present but that their use should not be encouraged. This group went on to recommend more research and greater effort on the development of energy sources which would not result in CO_2 release.

The DOE has initiated a major research program on the Greenhouse Effect under the leadership of David Slade. Detailed recommendations for this effort have been prepared by an Advisory Committee. These recommendations would have the DOE research program concentrate principally upon obtaining better information regarding the carbon cycle while research on climatic effects, including climate modeling, would be left up NOAA. Six programs for research on the carbon cycle are being recommended for immediate funding. These are presented in order of priority in Vugraph 16.

This immediate program would cost \$1.56 $\overline{MM}$ in the first year and would soon grow to about \$10 $\overline{MM}$ per year. The program to receive highest priority, is obtaining a better estimate of fossil fuel CO_2 output. This would involve a worldwide study of how fossil fuel combustion might be expected to increase and what would limit this increase in both the under-developed and developed countries. The second project relates to the use of carbon isotopes to obtain a better estimate of the input of carbon dioxide from the biosphere. It is hoped that C^{13}/C^{12} ratios as well as C^{14}/C^{12} ratios can be used for this purpose.

The third project is to obtain a direct assessment of the biosphere input by observing the growth or depletion of vegetated areas around the world from the Landstat satellites. High resolution radar and aerial photography will probably be required in some instances to identify vegetation types. The global vegetation map provided by these methods would be used to identify sample areas for 1) further analysis using photographs of higher resolution and 2) ground validation of vegetation and soil type to define the relationship between image characteristics and desired ground information. Two hundred to a thousand such areas would be identified and would be resurveyed at 2 to 5 year intervals in a program which would be expected to be able to detect a 2% change in the vegetation. This is an expensive program and would require about \$3 $\overline{MM}$ per year when it is running in full force.

The fourth project is to expand and improve the carbon dioxide monitoring network. This would involve adding 10 to 15 additional monitoring stations at suitably remote areas and expanding the instrumentation at all stations so that it could determine carbon isotope ratios.

The fifth project is to obtain better information on the transfer of carbon dioxide from surface waters into the deeper ocean. This would involve not only studies of CO_2 but also of tracers such as tritium, helium-3 and radiocarbon. This would require research with oceanographic ships and, when completely under way, would cost about \$5 MM/year. The last of the high priority programs for immediate funding is to obtain better information on the buffering of CO_2 absorption in the ocean.

After the initial programs are under way, the Advisory Committee is recommending that an additional effort involving seven more programs be established. These are listed, in order of priority, in Vugraph 17. The entire program would cost \$1.26 MM in the planning phase and would rise to \$5 MM/year when under way.

The first item in this program, and the seventh in the overall priority list, is to determine whether shallow water carbonates are dissolving because of CO_2 levels. The second item would be to obtain a better estimate of the response of the biota as a sink for additional carbon dioxide. The third in this program is to develop better models for the carbon cycle. Although modeling is an extremely important undertaking, it is placed ninth on the overall list because information from the earlier programs is needed for better model development.

Item number ten recommends a study and a better definition of the rate of carbon dioxide exchange across the interface between the air and the ocean. The next project would be to study the flux of organic carbon into and within the sea. Item number twelve is to develop improved carbon dioxide measurement techniques, while the final item on this list is to study the dissolution of deep sea calcium carbonate as a final sink for atmospheric carbon dioxide.

V. Summary

A summary of my talk is presented in Vugraph 18. In the first place, there is general scientific agreement that the most likely manner in which mankind is influencing the global climate is through carbon dioxide release from the burning of fossil fuels. A doubling of carbon dioxide is estimated to be capable of increasing the average global temperature by from 1° to 3°C, with a 10°C rise predicted at the poles. More research is needed, however, to establish the validity and significance of predictions with respect to the Greenhouse Effect. It is currently estimated that mankind has a 5-10 yr. time window to obtain the necessary information. A major research effort in this area is being considered by the U.S. Department of Energy.

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THE GREENHOUSE EFFECT

J. F. BLACK

TALK BEFORE

PERCC MEETING

MAY 18, 1978

BASIS FOR THE GREENHOUSE EFFECT

I. EARTH RECEIVES VISIBLE & UV RADIATION FROM SUN

A. Some Reflected Into Space
B. Some Absorbed By Atmosphere
C. Most Absorbed At Earth's Surface

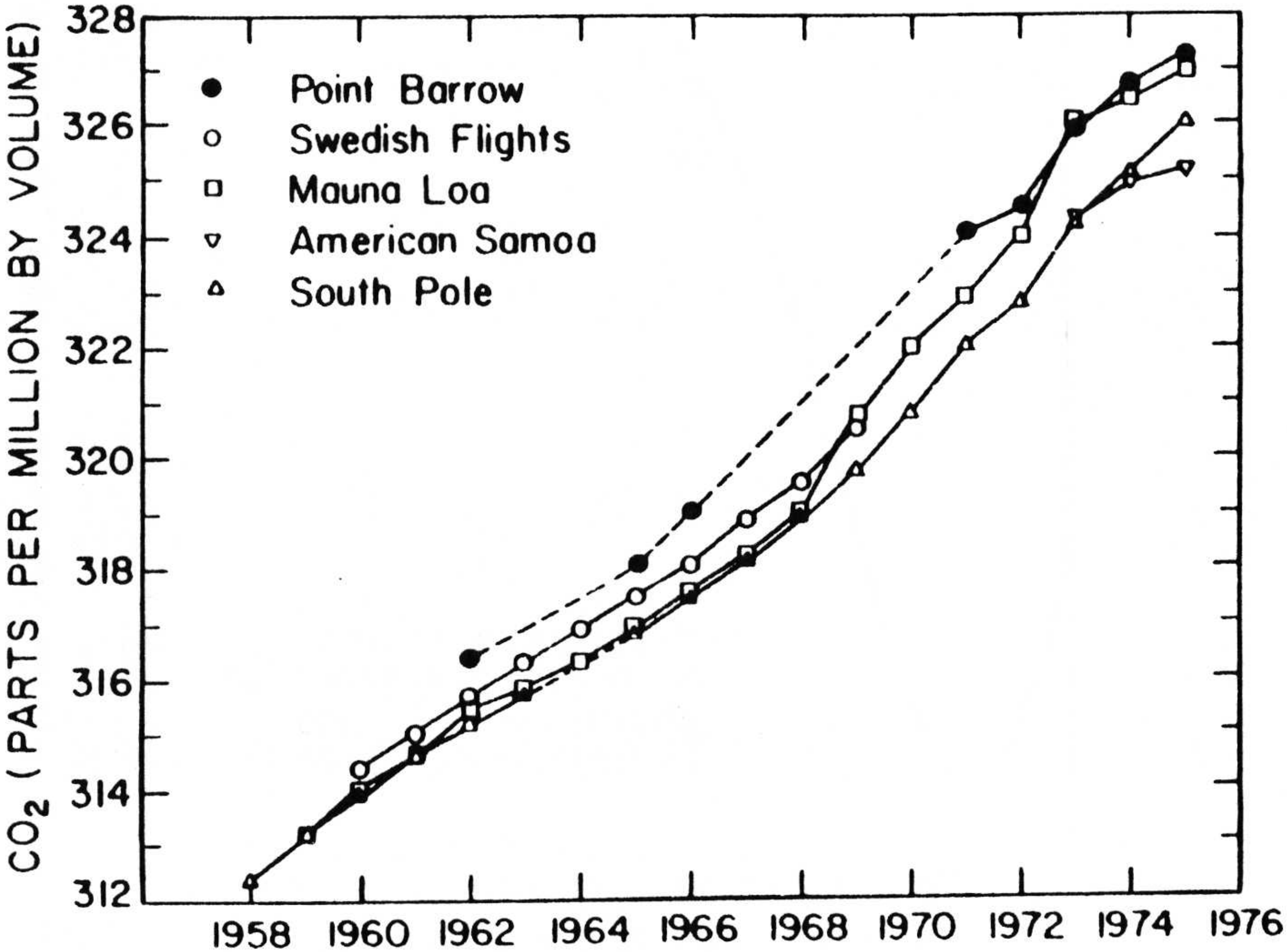
II. EARTH EMITS INFRARED RADIATION TOWARD SPACE

A. Carbon Dioxide And Other Atmospheric Constituents Absorb Part Of The Infrared Radiation
B. Absorbed Energy Warms The Atmosphere

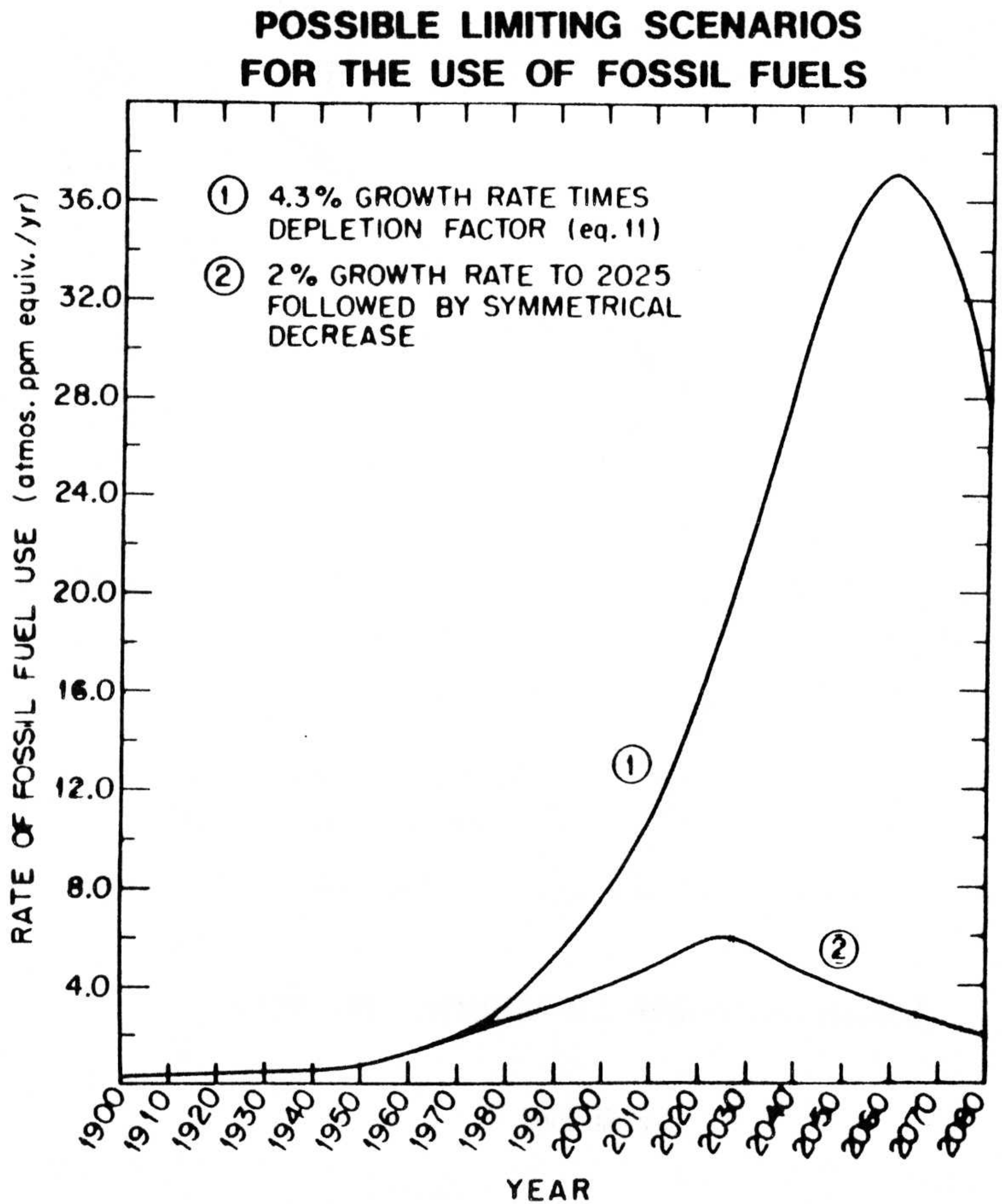
III. THEREFORE HIGHER CO_2 CONCENTRATIONS WARM THE LOWER ATMOSPHERE

VUGRAPH 2

CO_2 MEASURED AT REMOTE SITES



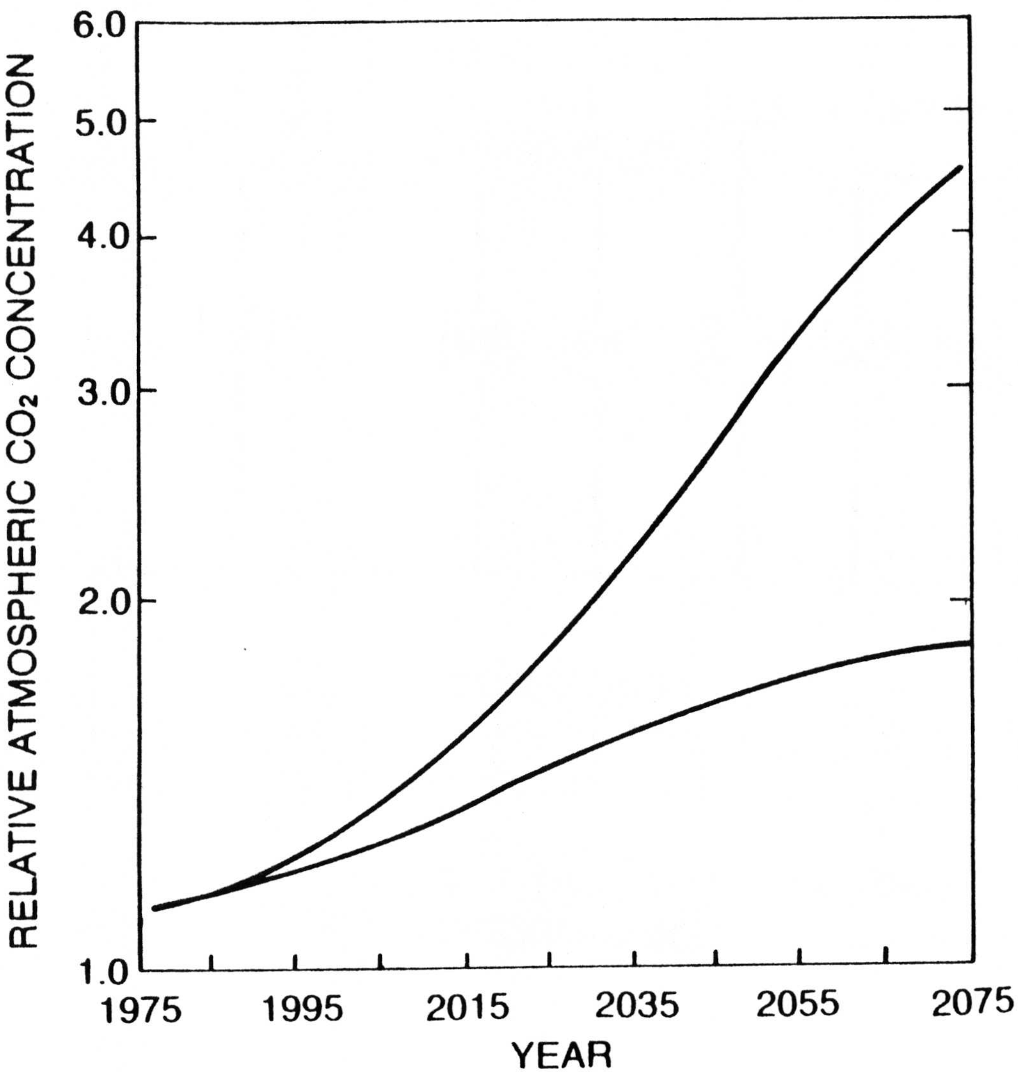
VUGRAPH 3



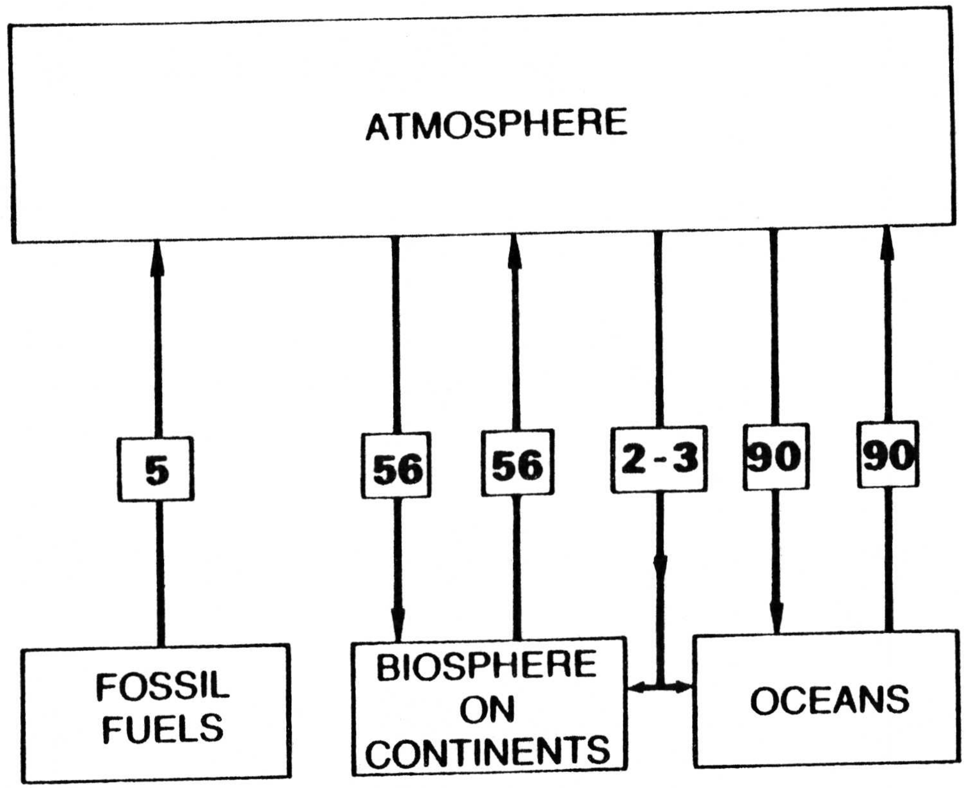
POSSIBLE LIMITING SCENARIOS
FOR THE USE OF FOSSIL FUELS
① 4.3% GROWTH RATE TIMES DEPLETION FACTOR (eq. 11)
② 2% GROWTH RATE TO 2025 FOLLOWED BY SYMMETRICAL DECREASE
RATE OF FOSSIL FUEL USE (atmos. ppm equiv./yr)
36.0
32.0
28.0
24.0
20.0
16.0
12.0
8.0
4.0
①
②
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
YEAR

VUGRAPH 4

PROJECTED ATMOSPHERIC CO_2 CONCENTRATIONS RELATIVE TO 1860



CO_2 EXCHANGE
(Billions Of Tons Of Carbon Per Year)



VUGRAPH 6

RATIO OF CO_2 DERIVED FROM BIOSPHERE VS FOSSIL FUEL

RATIO	1st AUTHOR	JOURNAL	DATE
0.1-1.0	ADAMS	SCIENCE	4/1/77
0.5	BOLIN	SCIENCE	5/6/77
0.8-1.6 (1)	WOODWELL	SCIENCE	1/13/78
2.0 (2)	STUVIER	SCIENCE	1/19/78
0.5	WILSON	NATURE	5/4/78

(1) PRESENT RATE (2) 1850-1950

CURRENT STATUS OF SCIENTIFIC OPINION

I. Current Opinion Overwhelmingly Favors Attributing Atmospheric CO_2 Increase To Fossil Fuel Combustion

II. Most Scientists Feel More Research Is Needed To Support An Unqualified Conclusion

III. Some Scientists Claim That Part Or All Of The CO_2 Increase Arises From The Destruction Of Forests And Other Land Biota.

UNCERTAINTIES WHICH LIMIT CLIMATE MODELING

I. CLOUDINESS

A. Effect Of A Cloud Depends On Size, Shape and Position.

II. ATMOSPHERE — OCEAN INTERACTIONS

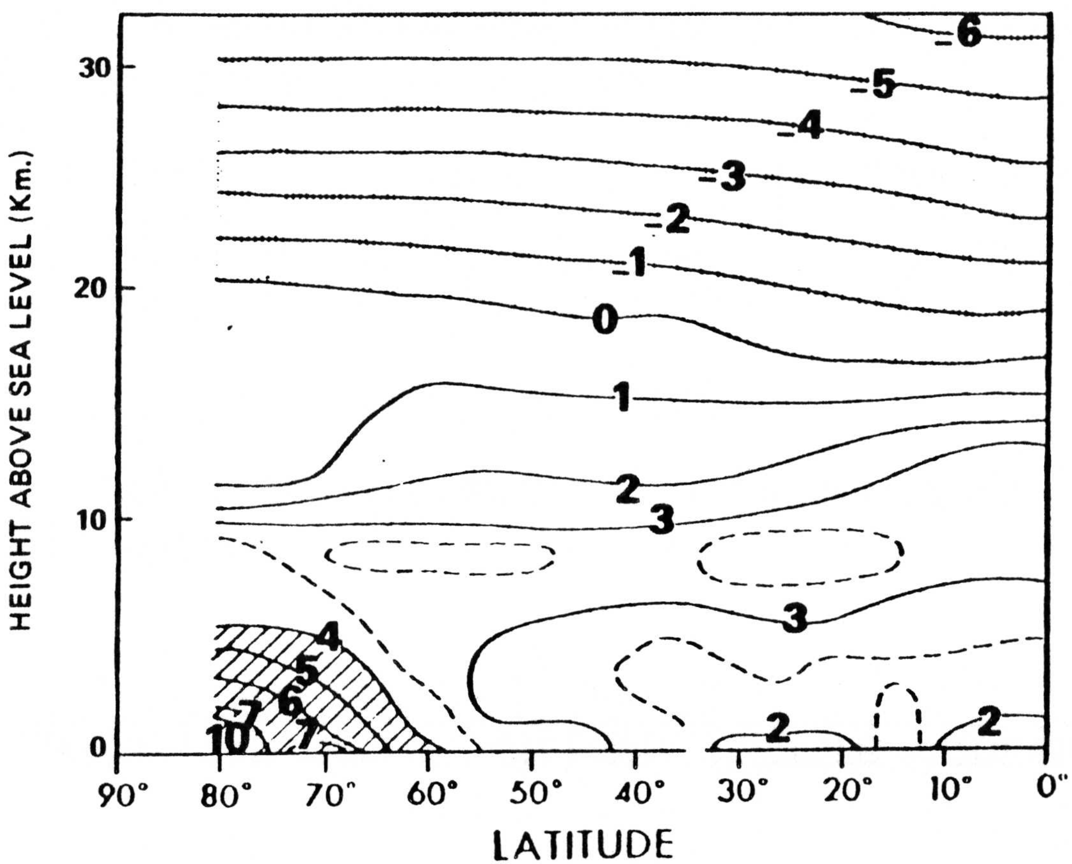
A. How Should Heat Capacity Be Handled
B. To What Depth Is The Ocean Involved

III. THE INTERACTION BETWEEN SEASONS AND LONG TERM TRENDS

IV. IS CLIMATE REALLY PREDICTABLE

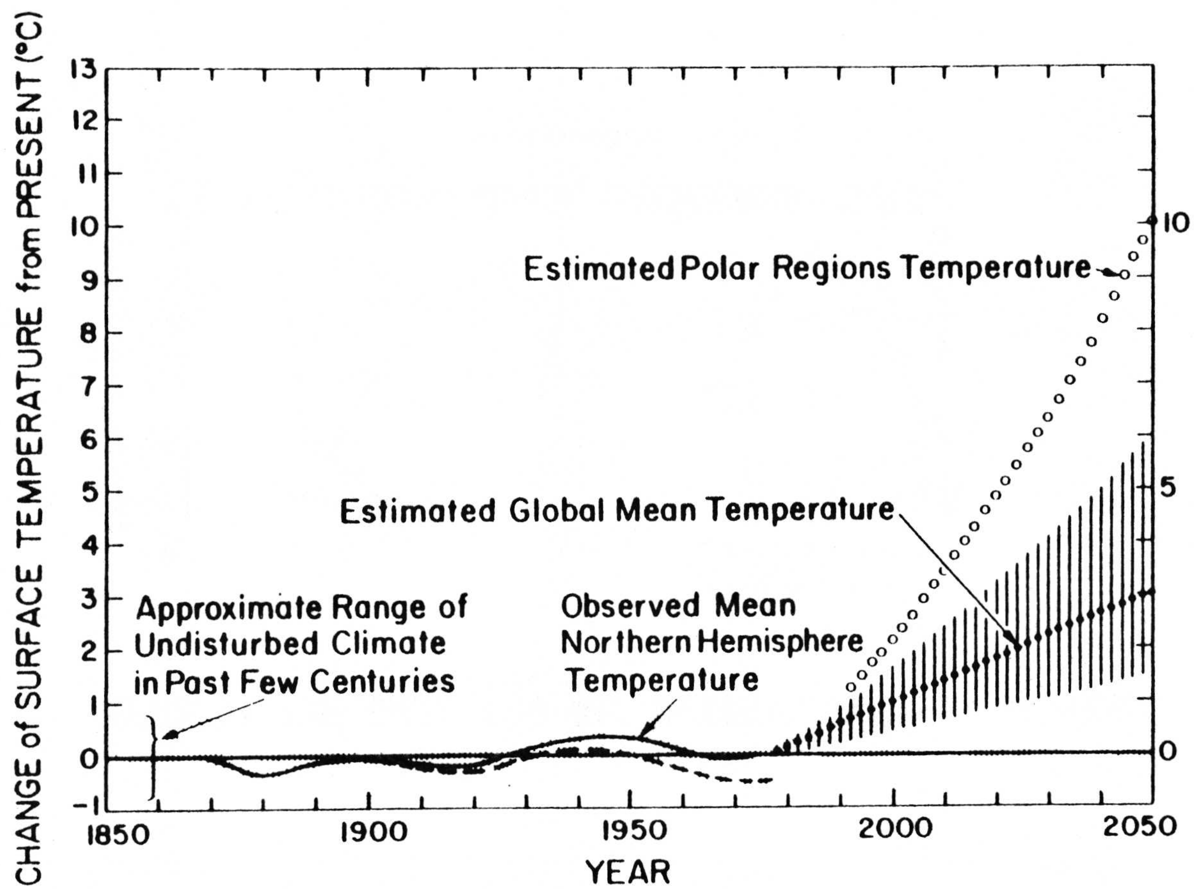
A. Could Be An "Almost Transitive " System Which Fluctuates Between Stable States.

TEMPERATURE EFFECT OF DOUBLING CO_2

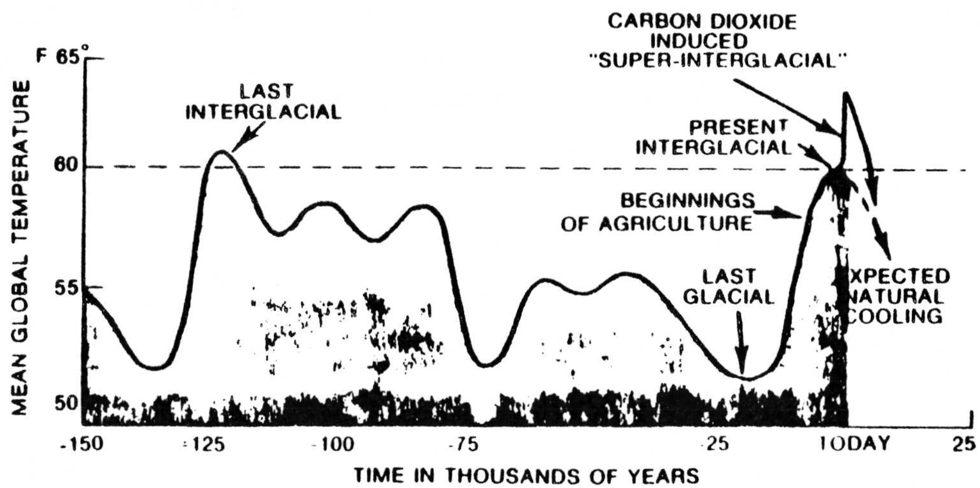


VUGRAPH 10

HOW PREDICTED ΔT COMPARES WITH RECENT TEMPERATURES



EFFECT OF CO_2 ON AN INTERGLACIAL SCALE



IMPLICATION OF PREDICTED GREENHOUSE EFFECT

I. **PERMANENT SNOW COVER AND FLOATING SEA ICE WILL BE REDUCED**
   A. Negligible Effect On Sea Level

II. **PROBABLY NO EFFECT ON POLAR ICE SHEETS**
   A. West Antarctic Ice Sheet Most Critical

III. **LENGTH OF GROWING SEASON WOULD INCREASE**
   A. 1°C Temperature Rise Adds 10 Days

IV. **CHANGES IN PRECIPITATION PATTERNS WILL BENEFIT SOME AREAS AND HARM OTHERS.**
   A. Models Can Not Predict These Effects
   B. Can Study Evidence From Climatic Optimum 4000-8000 Years Ago.


MOST OF THE USSR'S VAST
AGRICULTURAL LAND BASE
LIES LATITUDINALLY NORTH
OF THE UNITED STATES
Fairbanks
Leningrad
Kiev
Moscow
Arctic Circle
60
40
40
Minneapolis
Philadelphia
Washington
San Francisco
Denver
Springfield
SOVIET AGRICULTURAL LANDS

VUGRAPH 13

RECENT MEETINGS ON GREENHOUSE EFFECT

I. WORLD METEOROLOGICAL ORGANIZATION

SCIENTIFIC WORKSHOP ON ATMOSPHERIC CO_2

NOV. 28 - DEC. 3, 1976, WASHINGTON, D. C.

II. ERDA - WORKSHOP

ENVIRONMENTAL EFFECT OF CO_2 FROM FOSSIL FUEL COMBUSTION

MARCH 7-11, 1977, MIAMI BEACH, FLA.

III. SCOPE

WORKSHOP ON WORLD CARBON BUDGET

MARCH 21-26, 1977, HAMBURG, GERMANY

IV. IIASA

CARBON DIOXIDE, CLIMATE AND SOCIETY

FEB. 21-24, 1978, LAXENBURG, AUSTRIA

WORKING GROUP REPORTS - IIASA WORKSHOP

I. THE CARBON CYCLE

A. CONFIDENCE IN MODELS CONSIDERABLY LESS THAN 10 YEARS AGO

B. BIOSPHERE FLUX MUST BE ESTABLISHED

II. WHAT WILL BE CLIMATE IMPACT OF 2 X CO_2

A. 2-3°C INCREASE DEPENDING ON HOW CLOUDS ACT

III. CO_2 QUESTION VS. ENERGY STRATEGIES

A. MAN CAN AFFORD 5-10 YR. TIME WINDOW TO ESTABLISH WHAT MUST BE DONE.

B. IT IS PREMATURE TO LIMIT USE OF FOSSIL FUELS BUT THEY SHOULD NOT BE ENCOURAGED.

ERDA PROPOSALS FOR IMMEDIATE FUNDING

($1.56 $\overline{MM}$ TO START - SOON UP TO $9.8 $\overline{MM}$/YR.)

1. BETTER ESTIMATE OF FOSSIL FUEL CO_2 OUTPUT
2. USE CARBON ISOTOPES TO GET INPUT FROM BIOSPHERE
3. DIRECT ASSESSMENT OF BIOSPHERE INPUT ($3 $\overline{MM}$)
4. EXPAND AND IMPROVE MONITORING NETWORK
5. TRANSFER OF CO_2 INTO DEEPER OCEAN ($5 $\overline{MM}$)
6. BUFFERING OF CO_2 ABSORPTION IN OCEAN

PROJECTS STARTING AFTER INITIAL PROGRAMS ARE UNDER WAY

($1.26 $\overline{MM}$ TO START - RISES TO $5.0 $\overline{MM}$/YR)

7. ARE SHALLOW WATER CARBONATES DISSOLVING
8. RESPONSE OF BIOTA TO CO_2 INCREASE
9. BETTER MODELS OF CARBON CYCLE
10. CO_2 EXCHANGE ACROSS AIR-SEA INTERFACE
11. FLUX OF ORGANIC CARBON INTO & WITHIN SEA
12. IMPROVE CO_2 MEASUREMENT TECHNIQUES
13. DISSOLUTION OF DEEP SEA $CaCO_3$ AS FINAL SINK

SUMMARY

I. CO_2 RELEASE MOST LIKELY SOURCE OF INADVERTENT CLIMATE MODIFICATION.

II. PREVAILING OPINION ATTRIBUTES CO_2 INCREASE TO FOSSIL FUEL COMBUSTION.

III. DOUBLING CO_2 COULD INCREASE AVERAGE GLOBAL TEMPERATURE 1°C TO 3°C BY 2050 A.D. (10°C PREDICTED AT POLES).

IV. MORE RESEARCH IS NEEDED ON MOST ASPECTS OF GREENHOUSE EFFECT

V. 5-10 YR. TIME WINDOW TO GET NECESSARY INFORMATION

VI. MAJOR RESEARCH EFFORT BEING CONSIDERED BY DOE