Written Statement to the Congressional Oversight Committee by Dr. Edward A. Garvey

October 23, 2019

Thank you for the opportunity to speak before the committee. I am here to testify that Exxon considered rising CO_2 levels and the potential for CO_2-driven climate change to be of sufficient concern to commit to a significant research effort in 1978. I personally participated in the data collection for this research effort and I had first-hand knowledge of my management's objectives in collecting these data. I'd like to briefly describe to you some of the pertinent events of my five-year tenure with the Exxon Research and Engineering Company.

After graduating from college as a chemical engineer in July of 1978, I was hired to assist a senior scientist at Exxon (Dr. Henry Shaw) in the development of a greenhouse gas research project. Exxon scientists such as Dr. J. Black and Dr. Shaw has raised this as an issue to the corporation. I was told, by Dr. Shaw and possibly others, that Exxon undertook this research to earn itself a "place at the table" among scientists, policy makers, etc., regarding climate change and the potential responses to it. The research was intended to make an important contribution to the understanding of CO_2 and climate science. The program was also intended to constitute a uniquely Exxon contribution, something no other entity could readily do. In developing the program, we worked closely with Doctors Wallace S. Broecker and Taro Takahashi, geochemists with what was then the Lamont-Doherty Geological Observatory of Columbia University. (It is now known as the Lamont-Doherty Earth Observatory.) Dr. Shaw, and perhaps others at Exxon, felt that a joint investigation with well-respected researchers, such as these scientists, would lend credibility to the effort and also guarantee that the work would have substantive scientific importance. The Columbia scientists insisted that the findings be freely shared, without restrictions on their publications or on the scientists' non-project activities. As the work progressed, we would later add Dr. Ray Weiss of the Scripps Institute of Oceanography to the team of academics participating in the project. By working with leading scientists from academia and by conducting original and highly useful research, Exxon felt that its opinions would be taken seriously regarding greenhouse gases and possible solutions to the problem.

We ultimately selected a supertanker, the Esso Atlantic, to set up a dedicated monitoring system. At the time, the ship was the fourth largest ship in the world, a flagship of the Exxon International fleet, with a displacement of over 500,000 tons. The monitoring equipment would obtain measurements of CO_2 in surface water and in air as the ship traversed its normal routes. We permanently installed an extensive sampling system and a computer-based data collection system on the ship. The very large capacity of the ship meant the vessel was dedicated to the Gulf of Mexico - Persian Gulf route by way of Cape Horn of Africa. Thus, our equipment would cross equatorial zones in the central Atlantic and western Indian Oceans multiple times each year. Use of this ship on its dedicated route provided a high frequency sampling of the equatorial oceans and was viewed as a unique contribution from Exxon to the study of CO_2. The program's goal was to understand the role of the ocean in the global carbon cycle and its role in the storage of anthropogenic CO_2. Our study focused, in particular, on the cycling of CO_2 between the atmosphere and ocean in the equatorial region.

However, an oil tanker is not a research vessel, and on-board conditions were not designed to support the high precision instrumentation needed to conduct the study. Exxon expended a very significant development effort to design equipment capable of withstanding the harsh environment, going so far as to design and build a unique state-of-the-art gas chromatograph for CO_2 measurement, based on the analytical techniques developed by Dr. Weiss of the Scripps Institute. Exxon invested heavily in the project, spending over $900,000 per year at the program's peak (about $2.5M in today's dollars) and planned to make known its commitment to greenhouse gas studies. The video tapes of me on the ship that are now on the internet were made by professional photographers in 1979 with the intention of presenting the program to shareholders. The tanker project required the cooperation of multiple divisions within Exxon: the Exxon Research and Engineering Company (which employed Dr. Shaw and me), Exxon International (which scheduled and maintained the Esso Atlantic), and Exxon USA (which offloaded crews and equipment from the tanker in the Gulf of Mexico). Because of the degree of coordination among major wholly-owned companies as well as the scale of the research investment, it was my understanding that the Exxon corporate board was aware of the project and approved its implementation. I was told by my supervisors (Dr. Shaw and possibly others) that the project's progress was presented directly to the corporate board.

During the early stages of the planning, Exxon also considered other oil tanker routes that could provide similar opportunities to study ocean chemistry on a regular basis. Exxon hoped to get federal participation in this work, in part to get federal recognition of the importance of Exxon's research. We made a presentation to the then head of the Air Resources Laboratory (ARL) of the National Oceanic and Atmospheric Administration (NOAA), Lester Machta, in the hopes of winning federal participation. March 23, 1979). A copy of the presentation from the Exxon archives at the University of Texas-Austin is attached. The federal government chose not to participate, however, and Exxon funded the research entirely on its own for the next several years.

Exxon also considered a study to measure the dilution of atmospheric radiocarbon by fossil fuel CO_2 to augment the other lines of evidence that showed the growing prevalence of fossil fuel CO_2 in the atmosphere. It was our plan to measure carbon isotope levels in vintage wines going back to the 1850s. We consulted with Dr. Ralph Kunkee, a well-known professor in wine science at the University of California at Davis. Exxon chose not to pursue this line of research, but I mention it to emphasize how wide-ranging Exxon's thinking was at that time in considering how the company might contribute to climate science.

Around 1980 or so, unrelated to the tanker project, Exxon expanded its research efforts into climate modeling. They hired several scientists from academia, including Dr. Brian Flannery, to conduct this line of research. About 2 years later, the oil market, which had been quite lucrative for Exxon in the 1970s, collapsed. Exxon began to lay off staff across the corporation and also ended the tanker project abruptly, rather than winding it down in a way that would have allowed for processing, evaluation, and publication of the collected data. In particular, this meant that, although we had collected a lot of data, we had not yet fully processed it to obtain final values to support further analysis. To that point, we had only one published journal article on our work, a paper published in the peer-reviewed journal on Instrumentation and Measurement of the Institute of Electrical and Electronics Engineers (IEEE). which described the design and operation of the CO_2 monitoring equipment in the harsh environment on-board the tanker. I have included a copy of the article with this statement.

Although the reduction of the data into a workable format was not completed when the tanker project was discontinued, we were able to examine portions of the data set. We observed significant increases in oceanic CO_2 levels during our equatorial crossings relative to temperate ocean levels, confirming the predictions of oceanic surface concentrations by early models of CO_2 cycling. We also observed the plume of the Amazon River hundreds of miles offshore, a phenomenon that had not been previously documented.

Although Exxon discontinued the tanker project, it continued its climate modeling research, at least while I remained there. With the end of the project, the layoffs at Exxon and the lack of further support for my studies on the global carbon cycle, I opted to leave Exxon in 1983 and continue my graduate studies at Columbia, but in estuarine, rather than oceanic, geochemistry.

The years I spent at Exxon were an exciting time for research in general, and particularly for climate studies. Although we only published one journal article, the data we collected was ultimately incorporated into several papers concerning the global carbon cycle and the fate of increased anthropogenic CO_2 by the Columbia scientists. During my tenure there, I had the chance to work with some of the leading scientists in geochemistry and climate. Although I was very disappointed when Exxon discontinued the study, I am still grateful for the opportunity I was afforded.

In summary, the importance of my testimony is to note that Exxon knew of the anthropogenic climate change issue and considered it a sufficiently important problem to the company, and perhaps to society, that it funded and undertook a major research investigation of the world's atmospheric and oceanic CO_2 levels. While the research at Exxon did not continue long enough to fully analyze and interpret the results, the data we collected eventually became part of the scientific work published by Columbia scientists, further expanding the understanding of the ocean's role in CO_2 cycling and climate change. Although the corporation chose to discontinue this research, it continued to fund climate modeling research for at least several years after it terminated the tanker project. For the work that I was involved in, Exxon's efforts were intended to reduce the uncertainties associated with climate change forecasts and CO_2 cycling. In both instances, the corporation was well aware of the potential problem caused by rising CO_2 levels.

Exxon Global CO_2 Measurement System

EDWARD A. GARVEY, FRED PRAHL, KENNETH NAZIMEK, AND HENRY SHAW

***Abstract*—This paper describes a system designed to acquire atmospheric and surface-ocean pCO_2 data essential to the scientific study of air–sea CO_2 exchange, atmospheric CO_2 growth, and their variabilities. Highlighted is a computer-based measurement system installed aboard an oil tanker whose route traverses several oceans.**

I. Introduction

MANY SCIENTISTS have expressed concern over the recent observed growth of atmospheric carbon dioxide (CO_2) [1], [2]. As a result of this concern, the Exxon Research and Engineering Company, in cooperation with the Lamont–Doherty Geological Observatory of Columbia University, has begun a major program to study atmospheric CO_2 growth, ocean–atmospheric CO_2 exchange, and their seasonal and annual variabilities. A super tanker from the Exxon fleet, the "Esso Atlantic," is used to obtain data on atmospheric and oceanic CO_2 partial-pressure levels (pCO_2) and other parameters necessary to study these phenomena. The ocean and atmospheric parameters are monitored as the ship traverses its normal supply route. This paper presents a detailed description of how the monitoring system was designed to collect the needed data with sufficient precision in the hostile tanker environment. The initial data and findings of the study will be presented in subsequent publications.

II. The Measurement System

The measurement system was installed aboard the tanker "Esso Atlantic" (506 000 dead weight tons) which plies a route between the North Atlantic Ocean and the Persian Gulf via the Cape of Good Hope. By installing the system on a tanker as opposed to a dedicated oceanographic vessel, we are able to sample and study the same ocean areas six to eight times per year. By continuing the study for several years the system will provide data on the seasonal and year-to-year pCO_2 variations. In order to correctly interpret our pCO_2 measurements we must also monitor seawater salinity, seawater temperature, ambient humidity, latitude, longitude, and time.

The data requirements and hostile environment presented a multitude of challenges for the system including:

1) severe and varying vibration;
2) heat;
3) humidity;
4) audible noise;
5) seawater spray;
6) salt corrosion;
7) sample contamination from ship's exhaust gases;
8) safety;
9) high precision (ideally 0.2 percent for most measurements);
10) long data transmission lines;
11) 24-h continuous operation;
12) minimal maintenance;
13) long-term data storage in an easily retrievable form,
14) minimal manual data collection.

Based on these criteria, a computer-controlled sampling system was designed, centered in the ship's engine control room. This room is air conditioned and sound proofed thus providing the most protection for the electronics and the operator against noise, heat, corrosion, and moisture. Not all of the equipment could be located there, however. The remainder had to be constructed of special materials or enclosed in weatherproof housings. Table I lists the main equipment components and some of their specifications. Fig. 1 illustrates the flow of gas and electrical signals throughout the system.

The atmospheric pCO_2 measurement system contains over 500 m of tubing laid between four intake ports around the house of the ship and the main sampling manifold in the engine room. The sampling ports are positioned to provide atmospheric air samples free of contamination from the ship's stack gases regardless of the wind direction. Based on a signal from the ship's anemometer, the most upwind intake point is chosen by the computer for sampling. In addition, the remaining three lines are flushed with excess air from the intake line in order to keep them clean and free of moisture. The intake line is sampled at a high flow rate to keep the sample residence time to less than 2 min. This minimizes the effect of any contamination or moisture which may be inside the tube.

The ocean pCO_2 sampling system consists of a large seawater air contact chamber where seawater is mixed with air in a ratio of 115:1 (i.e., 0.115-m^3/min seawater flow and 0.001-m^3/min air flow). In this manner, the chamber operates at about 89-percent efficiency, i.e., the chamber will resolve 89 percent or more of the pCO_2 difference between the incoming air and the incoming seawater. The "equilibrated" air is then drawn off and measured by the CO_2 analyzer. The chamber is designed to operate close to atmospheric pressure (0.25-kPa gauge pressure) while still maintaining an air-tight seal. Air is supplied to the chamber as needed from the atmospheric air sampling system. Since the system is located at

Manuscript received November 1, 1981.
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0018-9456/82/0300-0032$00.75

TABLE I
INSTRUMENTATION

Instrument	Manufacturer	Precision/ Accuracy	Measurement Range	Shipboard ** Location	Output	Variable
Non-dispersive Infrared Analyzer	Mine Safety Appliances	1% F.S.	0-1000 ppm	ECR	0-1 ma	CO_2 Concentration by Volume
Barometric Pressure Sensor	Yellow Springs Instruments	0.15% F.S.	95-108 kPa (28-32 in Hg)	ER	0-10 V	Barometric Pressure
Ambient Temperature/ Dew Point Sensor	EG&G Environmental	± 0.4°C	-50°C to 50°C	ER/Outside	0-10 V	Atmospheric Air Temperature and Dew Point
Thermosalinograph	Ocean Data Equip.	± 0.03 ppt	18 to 38 ppt	ER	Serial	Salinity
Quartz Thermometer	Hewlett Packard	± 0.04°C	-50 to 150°C	ECR/ER	IEEE-488	Seawater Temperature
Real Time Clock	Hewlett Packard *	± 5 ppm	-	ECR	Internal I/O	Greenwich Mean Time
Computer	Hewlett Packard*	-	-	ECR	-	
Multiprogrammer	Hewlett Packard*	-	-	ECR	-	
Analog/Digital Card	Hewlett Packard*	50µV resolution	± 100 mV	ECR	-	
Analog/Digital Card	Hewlett Packard*	5 mV resolution	± 10 V	ECR	-	
Synchro/Analog Converter	Analog Devices*	5 mV resolution	± 180°	Bridge	-10 to 10 V	Wind Direction
Uninterruptible Power Supply	Clary*	-	-	ECR	1250 watts	

* Discussed in Section 3

** ER = Engine Room ECR = Engine Control Room

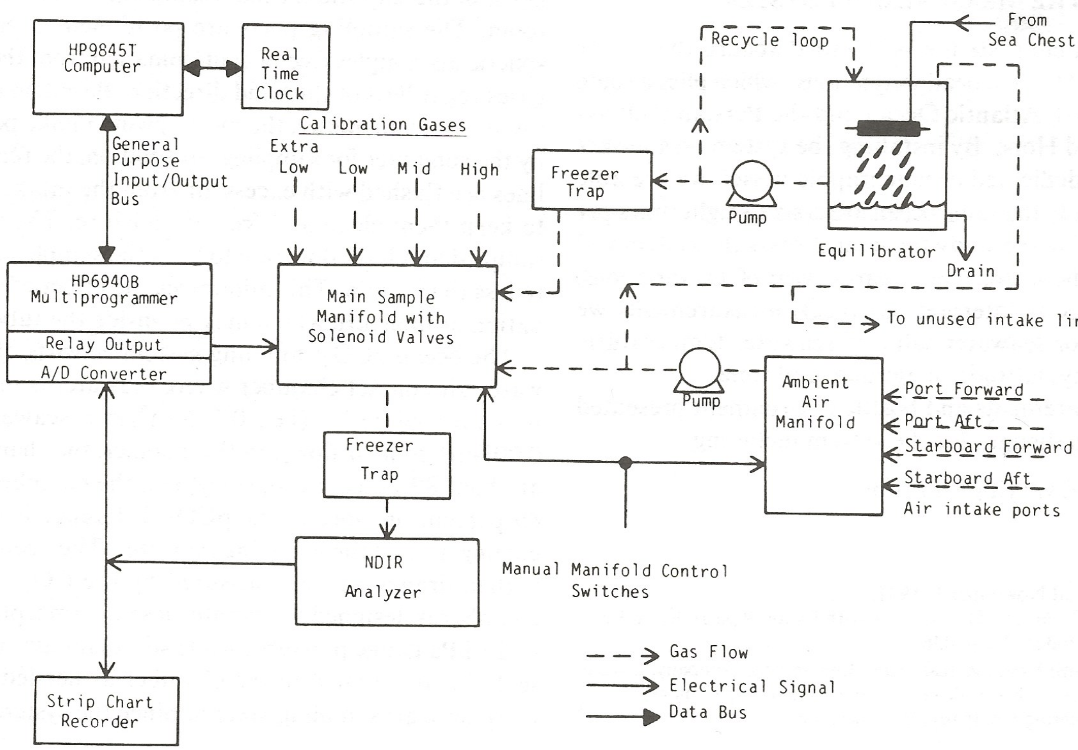

Fig. 1. Solenoid valve control/gas sampling system.

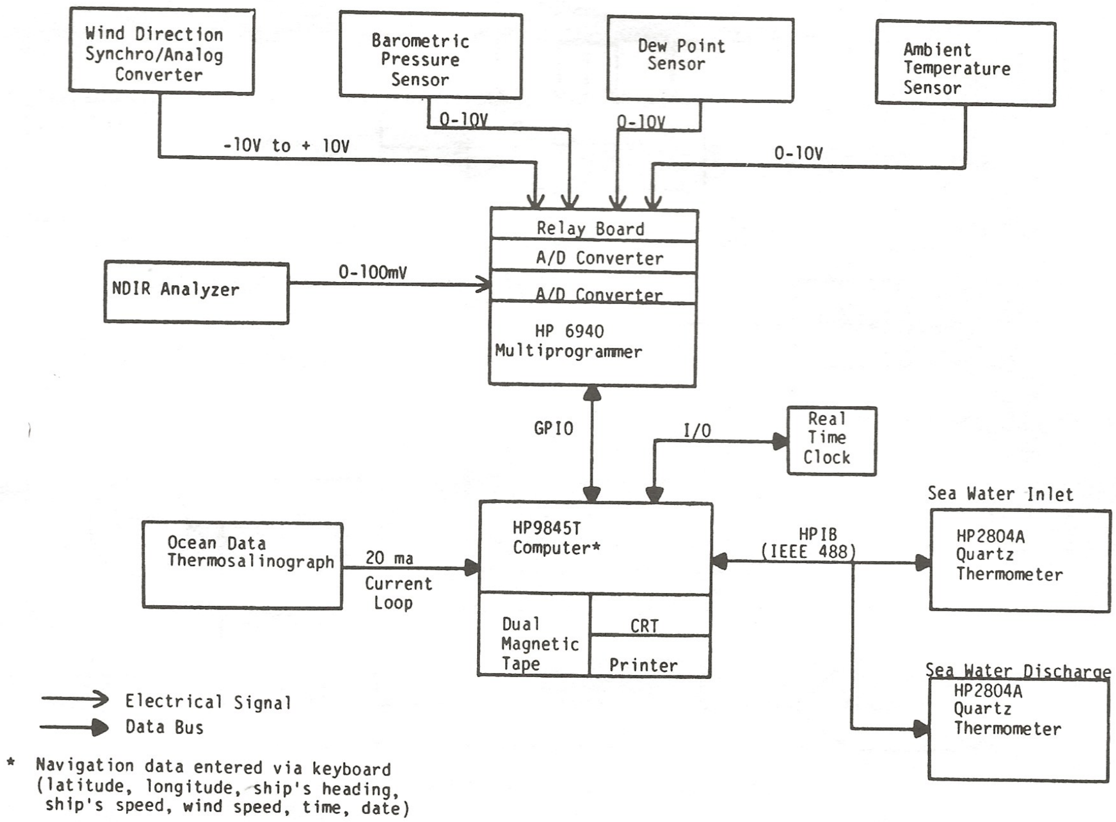

Fig. 2. Background and NDIR data acquisition.

the very bottom of the ship, a large recycle loop is used in order to provide a fresh sample to the main sample manifold with minimal flushing when required.

Premeasured calibration gases are used to calibrate the CO_2 measurement instrument, a nondispersive infrared analyzer (NDIR). They are supplied to the instrument via the main sample manifold. Three gases are selected so that their range encompasses the range of measured CO_2 concentrations. Calibration gases are available in approximately 20 ppmV or cm^3/m^3 intervals from 250 to 500 ppmV CO_2 in high-pressure air cylinders. The CO_2 concentration in each cylinder is accurate to approximately 0.45 ppmV (1σ). Further information on the NDIR-calibration technique can be found in Section III.

Of particular note in the system's design are the modifications made to the Mine Safety Appliances (MSA) instrument in order for it to achieve a higher level of precision. The instrument's optical path was unsealed and therefore sensitive to CO_2 within the instrument housing as well as within the sample cell. To prevent erroneous readings, CO_2-free gas is flushed continuously through the housing. On the ship, the analog output from the instrument was found to be extremely noisy, creating an erratic trace on the strip chart recorder and causing a significant decrease in instrument precision. Careful inspection uncovered several problem areas which require specific attention. Much of the erratic behavior was caused by the analyzer's microphone-type detector which proved to be extremely sensitive to the ship's vibration. To insulate the instrument from the ship's vibration, the analyzer was suspended from a steel frame by several shock cord supports while resting lightly on a foam rubber cushion. Additionally, a software filter routine, to be described in Section III, was employed to further increase analyzer precision. Due to the microvolt variations of the instrument's analog signal, it was further necessary to utilize special shielding and isolation techniques on low-level voltage sources while creating a system common reference point to eliminate unwanted ground loops. This overall process reduced the standard deviation voltage readings to less than 70 μV on a 45-mV signal level. The combination of these improvements with computer-operated calibrations have enabled us to achieve 0.3-percent precision full scale ($1\sigma = 1.7$ ppmV on 500 ppmV of CO_2).

III. System Control/Data Acquisition

Fig. 1 represents a simplified block diagram of the control and sample measurement systems. The main components of the control section are a Hewlett-Packard (HP) model 9845T desktop computer, an HP6940B Multiprogrammer, a real-time clock, a solenoid-activated manifold assembly, a Clary uninterruptible power supply, toggle switches for manual control of solenoids, and various input/output (I/O) cables for automatic control by the system computer. The sample measurement system is comprised of the NDIR, four calibration gas tanks, the equilibrated-air sampling system, and the ambient-air sampling system.

The sequencing of gases for measurement by the NDIR is controlled by the timing pulses generated from the real-time clock. During predetermined time intervals, a relay output module within the multiprogrammer is addressed by the computer to energize the appropriate solenoid valve. The selected gas is passed through the NDIR and the resultant millivolt signal is recorded by both the strip-chart recorder and

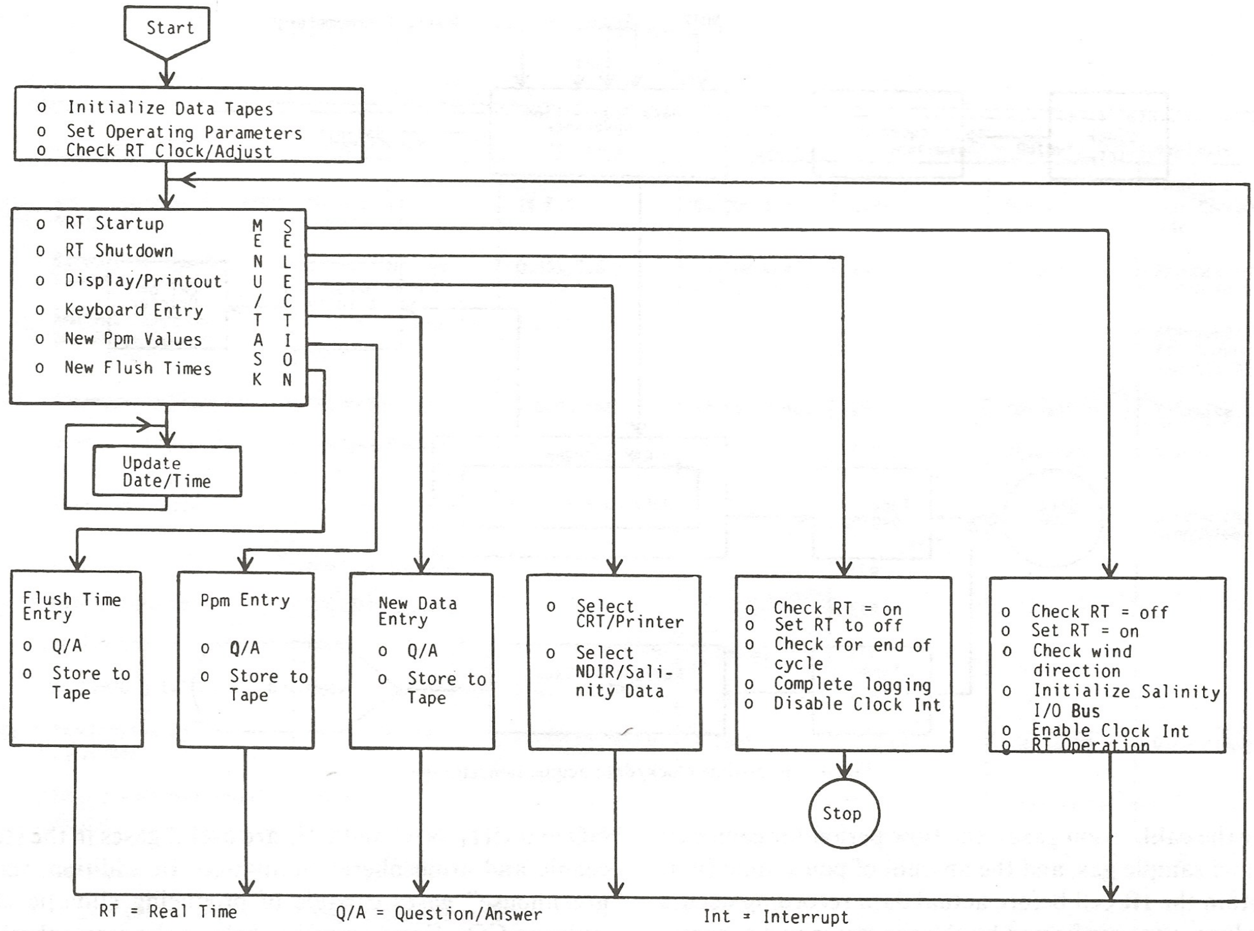

Fig. 3. Menu/special function selection.

the computer via an analog-to-digital (A/D) converter. Gases are sampled in a 12-step cycle, continuously repeated throughout the run. Each cycle is a fixed sequence of 12 gas flushes lasting a preselected period of time. Each flush period is followed by a 2- to 4-min pause period during which the flow is stopped and the NDIR is allowed to stabilize. The sequence of flushes permits a three point calibration at the start of each cycle by measuring low, middle, and high standard gases. Following the calibration gases are several equilibrated-air and ambient-air flushes. The middle calibration gas is flushed again at mid-cycle to monitor the zero drift of the NDIR. The CO_2 measurement, taken during each of the 12 steps, is derived in a special routine that was designed to filter the noise caused by the inherent shipboard vibration. A software routine takes 5000 readings over a 1-min span, via a high-speed A/D converter (50-μV resolution). The routine also determines their mean and standard deviation and stores the results for later processing.

Fig. 2 depicts the measurement/data acquisition portion of the system. Analog information representing the wind direction, barometric pressure, dew point, and atmospheric temperature is always present at the input to a relay board to be digitized by a high-speed A/D converter. Salinity, conductivity, and temperature data are continuously generated by the thermosalinograph on a 20-mA current loop and are readily available to be read by the computer when appropriate. The quartz thermometer readings are sent directly to the computer via a Hewlett-Packard interface bus (HPIB) when interrogated by the software. During the individual pause periods in the sampling cycle, the appropriate signals corresponding to the type of gas in the NDIR cell (e.g., ambient air, low-calibration gas) are collected by the computer. These data and the NDIR reading are stored in memory for further processing.

Routines at the completion of the second and subsequent cycles correct NDIR voltage levels if analyzer drift has occurred. The corrected values and the appropriate sample gas values of the preceding 12-step cycle are further manipulated by a quadratic curve fit routine to determine the sea and air CO_2 ppmV values. Finally, pCO_2 values are calculated from the results of the curve fit routine and the respective background data. All computed, corrected, and background data are stored in random-access memory (RAM) for operator review and on magnetic tape for further processing using land-based mainframe computers.

Figs. 3 and 4 show the system software, which was designed to provide a friendly operating system for noncomputer-oriented operators. Other considerations in the basic design were to allow the user to interact with the computer, enable system response through hardware and software interrupts, and permit unattended operation of the measurement control system.

At startup, the operator is prompted to respond to a series of questions which ultimately set the system's operating parameters. These questions request the CO_2 concentration

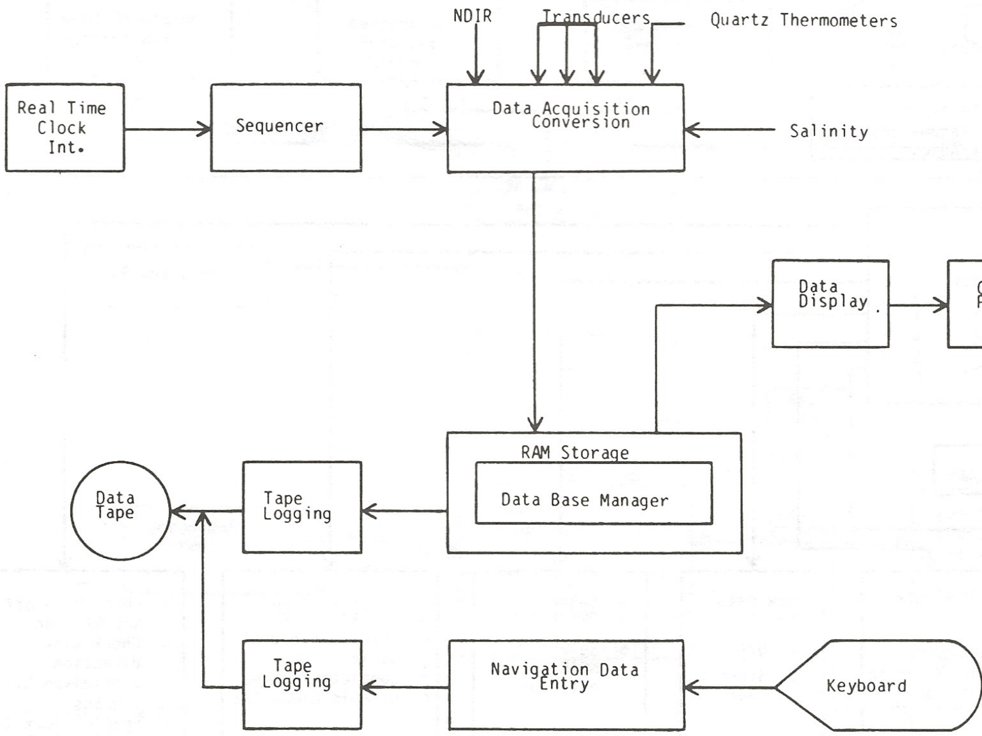

Fig. 4. Real-time clock/data acquisition/storage.

values of the calibration gases, the flow period for each calibration and sample gas, and the amount of pause time (non-flow) within the IR cell before actual data recording occurs. These values, once confirmed by the computer and accepted by the operator, are permanently stored on tape. After assigning data storage space to the tape and checking the accuracy of the real-time clock, a list of operational tasks is displayed on the cathode-ray tube (CRT) for selection by the operator via special function keys. These tasks include measurement system startup, operating parameter changes, hard-copy printouts of stored data, and measurement system shutdown. When not used for other purposes, the CRT displays GMT time.

The operating system is designed to respond to software (program statements), hardware (I/O devices), and error interrupts. When an interrupt occurs, the computer reacts by determining the type of interrupt and selecting the appropriate configured service routine. Priorities are assigned to the various interrupts to establish the order in which simultaneous interrupts and I/O devices of greater importance are handled. A data-base manager was designed to provide storage for a huge amount of data in an orderly fashion. This facilitates other routines that are called upon to generate reports from its stored contents.

IV. Future Plans

Based on about two years of operation, the system has been relatively successful in meeting our goals and requirements. However, the need for precision was a particularly difficult requirement to meet. As a result, several additions have been made and we are continuing to improve the system. In July 1981, a gas chromatograph was added to the CO_2 measurement system to improve its precision and to provide data on N_2O and CH_4. N_2O and CH_4 are useful gases in the study of oceanic and atmospheric circulation. In addition, they are "greenhouse" gases capable of producing climatic change similar to CO_2. Some scientists believe the atmospheric concentration of these gases are increasing via man-made sources and thus should be monitored. We hope to publish the results from our chromatographic work in the near future.

Acknowledgment

The authors would like to give special thanks to M. Kirk, A. Guarino, T. Pugel, D. Danik, and Mrs. S. Gregory whose contributions, both on the tanker and in the laboratory, have made the program successful. They would also like to thank Dr. T. Takahashi and Dr. W. S. Broecker of the Lamont–Doherty Geological Observatory, and Dr. R. Weiss of the Scripps Institute of Oceanography whose guidance throughout the program, especially in the design of the sampling system, has helped them greatly. Special thanks is given to R. A. Halko and the staffs of the Research Technology Services Division and the Computing Technology Services Division of Exxon Research and Engineering Company for their assistance. They are also grateful to P. Kimon and the Exxon International Tanker Department, whose cooperation and vessel have made this program possible. Finally, they would like to thank CPT Schiappacasse, Chief Engineer Gargulo, and the crew of the "Esso Atlantic" for making their work as easy and pleasant as possible.

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[1] H. Flohn, "Possible climate consequences of a man-made global warming," II ASA Tech. Rep. RR-80-30, 1980.

[2] J. G. Chaney *et al.*, "Carbon dioxide and climate: A scientific assessment," *Nat. Acad. Sci.*, 1979.

PROPOSED EXXON RESEARCH PROGRAM TO HELP ASSESS THE GREENHOUSE EFFECT

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TARO TAKAHASHI

PRESENTED TO:

DR. LESTER MACHTA
AIR RESOURCES LABORATORY
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

MARCH 26, 1979

PROGRAM GOAL

- USE EXXON EXPERTISE AND FACILITIES TO HELP DETERMINE THE LIKELIHOOD OF A GLOBAL GREEN-HOUSE EFFECT

RATIONALE FOR EXXON INVOLVEMENT

- DEVELOP EXPERTISE TO ASSESS THE POSSIBLE IMPACT OF THE GREENHOUSE EFFECT ON EXXON BUSINESS

- FORM RESPONSIBLE TEAM THAT CAN CREDIBLY CARRY BAD NEWS, IF ANY, TO THE CORPORATION

- PROVIDE THE GOVERNMENT WITH HIGH QUALITY INFORMATION TO REDUCE THE BUSINESS RISK OF INADEQUATE GOVERNMENT POLICY

- GENERATE IMPORTANT SCIENTIFIC INFORMATION THAT WILL ENHANCE THE EXXON IMAGE AND PROVIDE PUBLIC RELATIONS VALUE

DOE INTEREST

- ACCELERATE CONTEMPLATED RESEARCH PROGRAM IN OCEANIC CO_2 MEASUREMENTS
- COST EFFECTIVE METHOD TO ACQUIRE ESSENTIAL OCEANOGRAPHIC DATA
- OBTAIN INDUSTRIAL PARTICIPATION TO COMPLEMENT CURRENT ACADEMIC EFFORT
- CONTRIBUTION OF DATA FROM EXXON FUNDED PROGRAMS TO DETERMINE SOURCE OF CO_2 IN ATMOSPHERE AND AIR-OCEAN CO_2 MASS TRANSFER COEFFICIENTS

DEFINITION

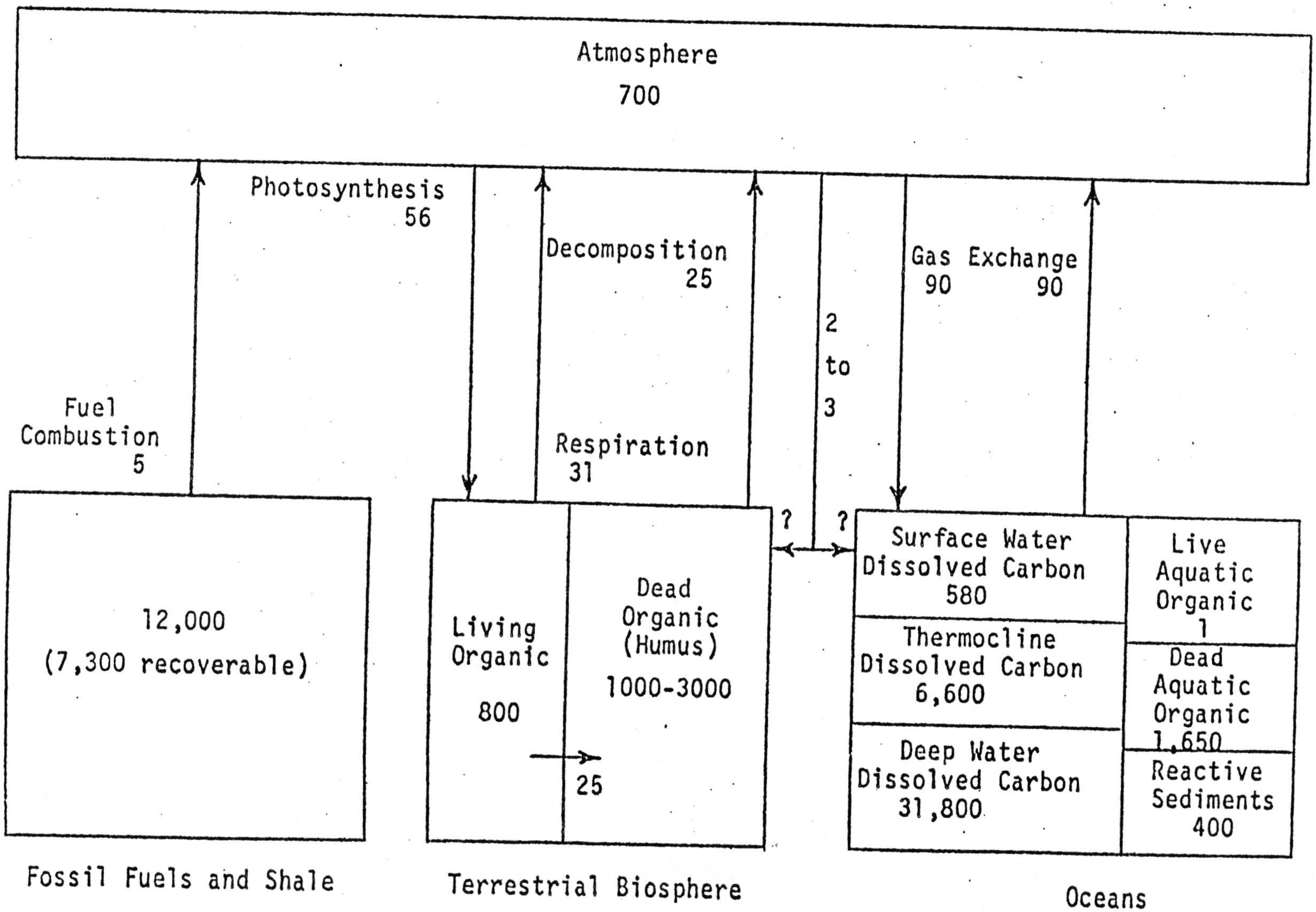
GREENHOUSE EFFECT - AN UPSET IN THE EARTH'S THERMAL BALANCE CAUSED BY THE REABSORPTION OF INFRARED RADIATION FROM THE EARTH BY THE INCREASING LEVELS OF CO_2 AND OTHER ATMOSPHERIC COMPONENTS

- ATMOSPHERIC CO_2 HAS INCREASED 15% SINCE THE INDUSTRIAL REVOLUTION
- THE ANNUAL ANTHROPOGENIC ADDITION OF CO_2 TO THE ATMOSPHERE HAS BEEN INCREASING AT 4% PER YEAR SINCE THE INDUSTRIAL REVOLUTION
- THIS INCREASE HAS BEEN ATTRIBUTED TO FOSSIL FUEL UTILIZATION
- APPROXIMATELY 10-15% OF THE CO_2 FROM FOSSIL FUELS CANNOT BE ACCOUNTED FOR
- ATMOSPHERIC CO_2 CONTRIBUTION FROM FOREST CLEARING IS NOT KNOWN

The Carbon Cycle

1978

Fluxes in Gt/a
Pool sizes in Gt



MAJOR RESEARCH NEEDS

PROBLEM AREA	RESEARCH NEEDS	EXXON CAPA- BILITY
ATMOSPHERE	- WEATHER MODELING	NO
	- DISPERSION OF CO_2	YES
OCEAN	- INTERLAYER EXCHANGE OF CO_2	YES
	- CIRCULATION OF SEAWATER	YES
TERRESTRIAL BIOSPHERE	- STORAGE AND EXCHANGE OF CARBON	YES
INTER-AREA EXCHANGE	- CO_2 EXCHANGE ACROSS OCEAN-ATMOSPHERIC INTERFACE	YES
	- CO_2 EXCHANGE BETWEEN BIO-SPHERE AND ATMOSPHERE	

PROPOSED PROGRAMS

PROGRAMS	FUNDING
OCEAN SAMPLING PROGRAM	
- TANKER SAMPLING SYSTEM	DOE/EXXON
- DRILLING SHIP STATION	EXXON
LAND BIOTA SAMPLING PROGRAM	
- C-13 AND C-14 SAMPLING	EXXON

OBJECTIVES OF OCEAN SAMPLING

- DETERMINE CO_2 FLUX BETWEEN AIR AND OCEAN

  FLUX = (TRANSFER COEFFICIENT) X (DRIVING FORCE)

  DRIVING FORCE DETERMINED FROM TANKERS AS A FUNCTION OF $CO_{2_{ATM}}$, $CO_{2_{SW}}$, TEMPERATURE, LOCATION, ETC.

  TRANSFER COEFFICIENT DETERMINED FROM DRILLING SHIPS BY TRACER STUDY AS A FUNCTION OF WEATHER, SEA-STATE, ETC.

- CROSSCHECK RATE OF CO_2 EXCHANGE ACROSS THE AIR-SEA INTERFACE USING C-14 RELEASED DURING ATOMIC BOMB TESTS AS TRACER

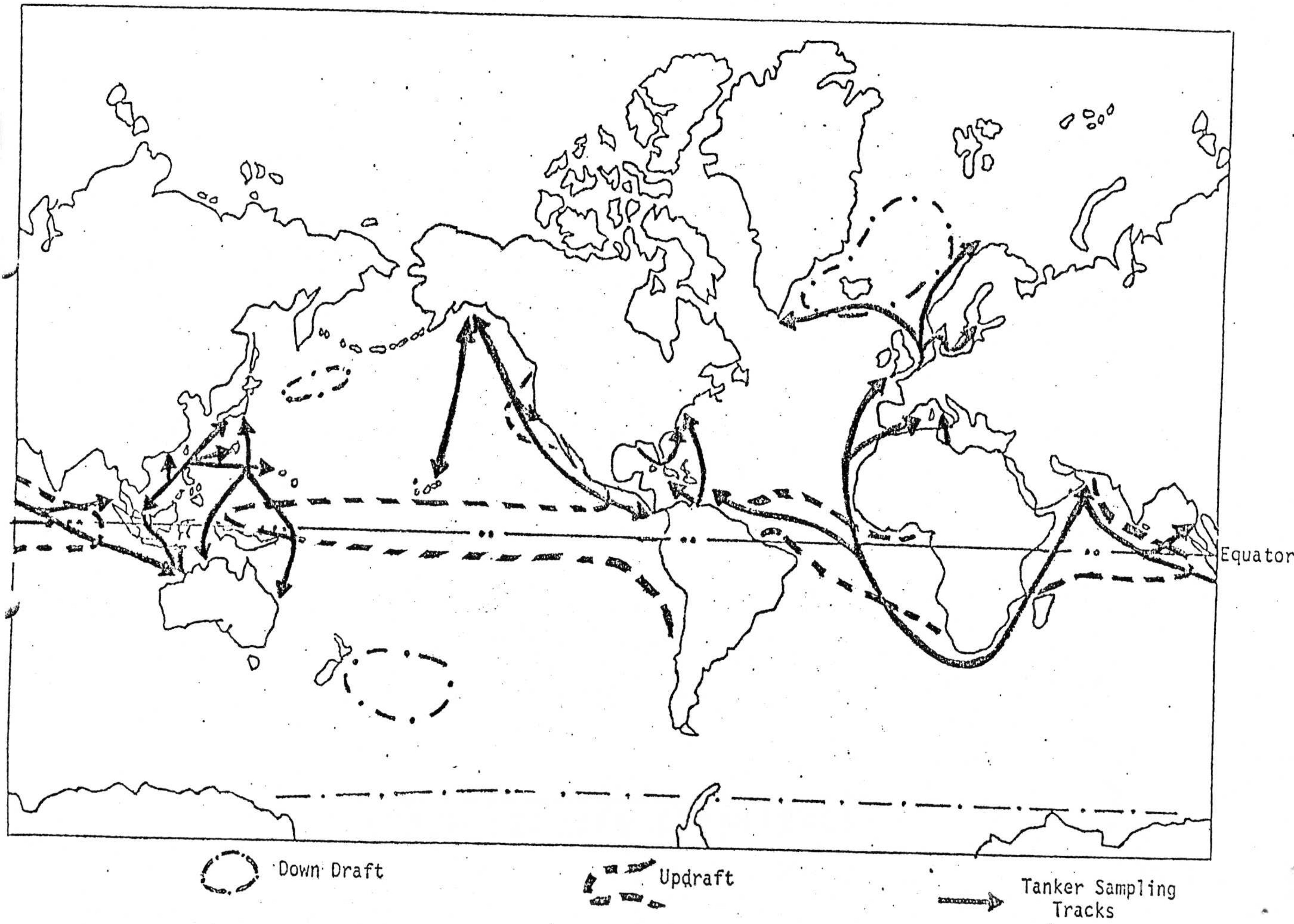
TANKER PROGRAM

- TANKERS WILL SAMPLE CONTINUOUSLY
  - ATMOSPHERIC CO_2 TO ± 0.5 PPMV
  - OCEAN CO_2 TO ± 0.5 PPMV
  - SEA AND AIR TEMPERATURE TO ± 0.1°C
  - RELATIVE HUMIDITY
  - BAROMETRIC PRESSURE
  - SALINITY
  - SEAWATER pH
- TANKER WILL ALSO SAMPLE SURFACE SEAWATER FOR C-14 ON A PERIODIC BASIS
- DEPTH THERMOMETERS WILL BE USED PERIODICALLY TO DETERMINE THE TEMPERATURE PROFILE OF THE OCEAN ALONG THE TANKER ROUTE

TANKER PROGRAM (CONTINUED)

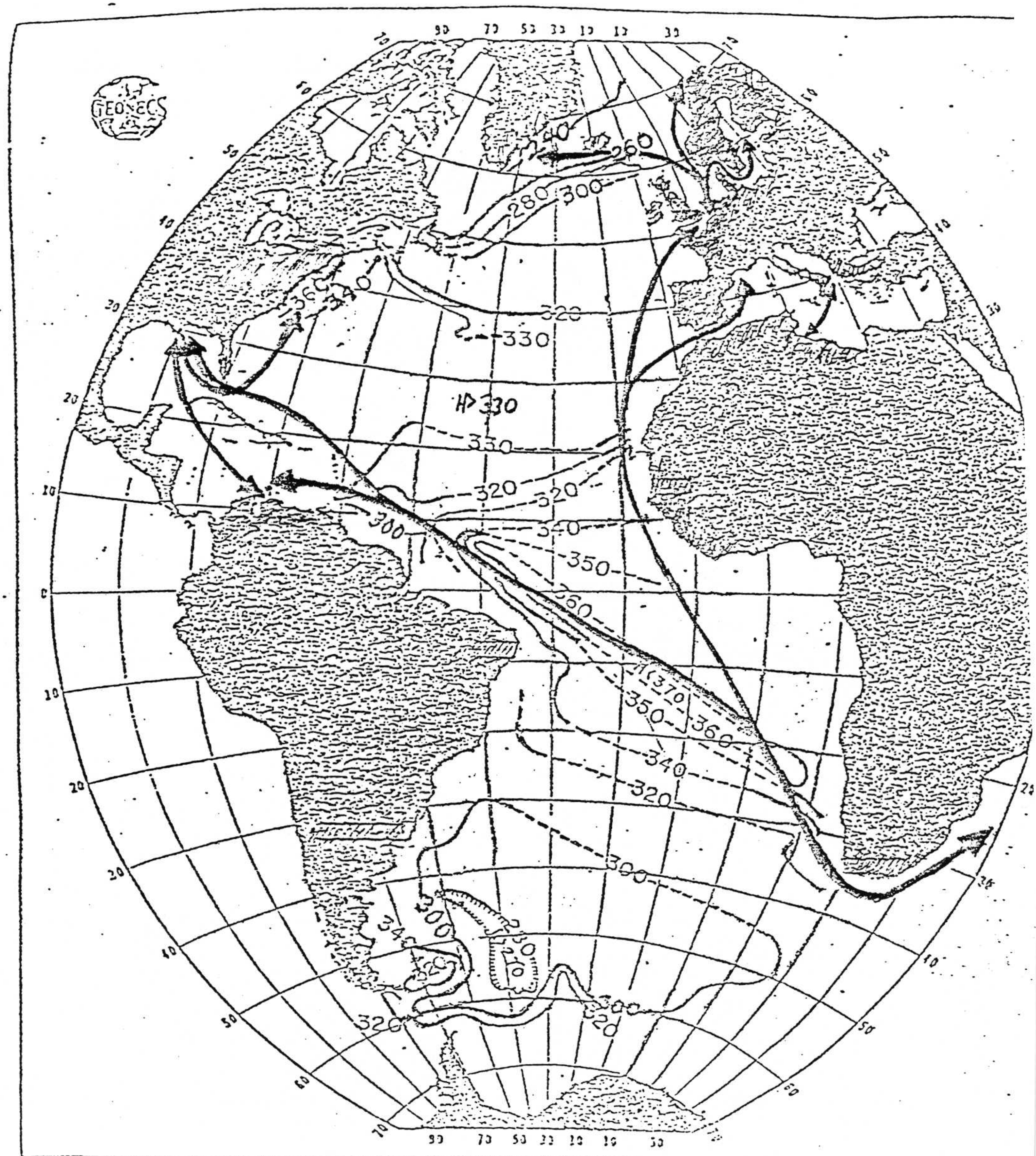
- TANKER WILL BE ABLE TO REPEAT MEASUREMENTS ALONG A PARTICULAR ROUTE ANYWHERE FROM 10 TO 40 TIMES PER YEAR DEPENDING ON ROUTE LENGTH AND PETROLEUM DEMAND
- TANKER PROGRAM WILL BE EXPANDED FROM ONE ROUTE DURING THE FIRST YEAR TO FIVE BY THE THIRD YEAR
- SOME TANKER ROUTES PROPOSED IN THIS PROGRAM CROSS AREAS WHERE RELATIVELY LITTLE OCEANOGRAPHIC WORK HAS BEEN DONE
- THE DATA COLLECTED WILL BE USED TO DETERMINE pCO_2 LEVELS ON A REGIONAL AND SEASONAL BASIS IN BOTH THE ATMOSPHERE AND THE OCEANS

DEEP WATER WELLINGS AND TANKER ROUTES



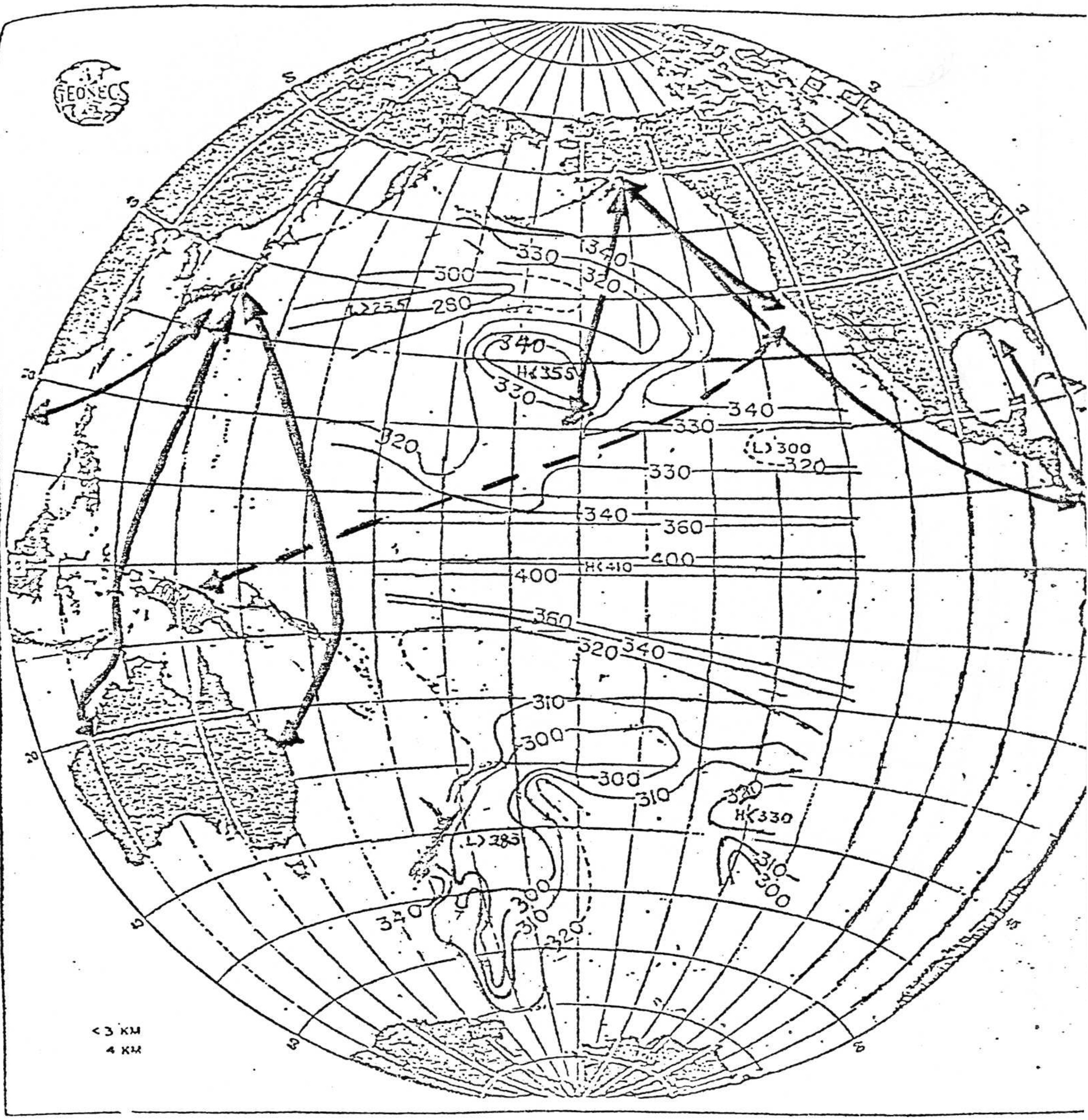
pCO_2 10^{-6} atm. IN THE SURFACE WATER OF THE ATLANTIC OCEAN

JULY 1972 - MARCH 1973



All Exxon Atlantic tanker routes.

pCO_2 10^{-6} atm. IN THE SURFACE WATERS OF THE PACIFIC OCEAN
AUGUST 1973 - JUNE 1974



Pacific tanker routes.

Exxon routes — Other tanker routes

DRILLING SHIP PROGRAM

- EXXON CONTRACTED DRILLING SHIPS ARE PRESENTLY EXPLORING MANY DEEP WATER AREAS AROUND THE WORLD
    - DRILL IN OCEAN DEPTHS WELL OVER 1000 FEET, SOMETIMES AS MUCH AS 5000 FEET
    - REMAIN IN ONE LOCATION FOR TWO TO THREE MONTHS

- AT THESE DEPTHS, THE OCEAN IS USUALLY WELL STRATIFIED, AND IS SUITABLE FOR TRACER GAS STUDY

DRILLING SHIP PROGRAM (CONTINUED)

- MEASUREMENT OF SURFACE WATER RADON-222 PROFILES AND WEATHER DATA CAN BE USED TO DETERMINE THE RATE OF GAS EXCHANGE AS A FUNCTION OF WIND SPEED AND SEA STATE

- DEEP WATER SAMPLING CAN ALSO BE PERFORMED TO ENHANCE OUR UNDERSTANDING OF DEEP OCEAN EXCHANGE OF CO_2, RADON-222, AND OTHER CHEMICAL TRACERS

INFORMATION YIELDS

TANKER PROGRAM

- THE FOLLOWING DATA WILL BE COLLECTED ALONG THE TANKER ROUTES:
  - ATMOSPHERIC pCO_2
  - OCEANIC pCO_2
  - SEA TEMPERATURE PROFILES
  - SALINITY
  - pH
  - SURFACE WATER CARBON-14 LEVELS

- USING THE ABOVE DATA TO MAP SEASONAL AND REGIONAL VARIATIONS WILL ENHANCE OUR UNDERSTANDING OF:

INFORMATION YIELDS (CONTINUED)

- ATMOSPHERIC CIRCULATION
  + THE VARIATIONS WILL HELP DETERMINE GLOBAL AIR CIRCULATION PATTERNS AND COULD BE A USEFUL CONTRIBUTION TO THE TRANSIENT TRACES PROGRAM NOW BEGINNING UNDER DOE FUNDING
- OCEANIC pCO_2
  + WILL BE USED TO ESTABLISH GLOBAL SEAWATER CIRCULATION PATTERNS
  + BY CROSSING UPWARD AND DOWNWARD ADVECTION ZONES THE SEASONAL AND YEARLY EXCHANGE OF SURFACE AND DEEP WATER WILL BE MONITORED
- OCEANIC AND ATMOSPHERIC pCO_2
  + WILL BE USED TO ESTABLISH THE CONCENTRATION GRADIENT ACROSS THE INTERFACE

INFORMATION YIELDS (CONTINUED)

  + THE CONCENTRATION VARIATIONS ACCORDING TO SEASON AND REGION WILL BE USED TO GENERATE MORE ACCURATE CO_2 EXCHANGE MODELS
- OCEAN TEMPERATURE PROFILES
  + WILL BE USED TO DETERMINE THE THICKNESS OF THE SURFACE WATER LAYER AND ITS VARIATION ACCORDING TO SEASON AND REGION
  + THIS WILL PROVIDE ADDITIONAL INFORMATION ON OCEAN CIRCULATION PATTERNS AND WIND EFFECTS ON OCEAN MIXING
- SALINITY
  + WILL BE USED TO DEFINE OCEAN WATER MASSES
  + IT IS ALSO USED TO CORRECT THE RAW pCO_2 MEASUREMENTS

INFORMATION YIELDS (CONTINUED)

- pH WILL BE USED TO DETERMINE TOTAL INORGANIC CARBON
- SURFACE WATER C-14 LEVELS
  + WILL BE USED AS AN ALTERNATIVE METHOD OF CHECKING THE OCEAN-AIR CO_2 EXCHANGE
  + SEASONAL AND YEARLY TIME TRENDS OF C-14 LEVELS IN THE UPWARD ADVECTION ZONES WILL BE USED TO MEASURE CARBON PENETRATION AND COMPLEMENT THE TRANSIENT TRACER PROGRAM IN THIS AREA

INFORMATION YIELDS (CONTINUED)

DRILLING SHIP PROGRAM WILL BE USED TO:

- OBTAIN A RELATION FOR THE GAS EXCHANGE COEFFICIENT OF A NON-REACTIVE GAS WITH WIND SPEED AND SEA STATE
- DETERMINE NEEDED CORRECTIONS FOR CO_2 REACTIVITY
- THE GAS TRANSFER COEFFICIENT FUNCTION WILL BE USED WITH THE REGIONAL AND SEASONAL pCO_2 MEASUREMENTS AND PREVAILING LOCAL WEATHER CONDITIONS TO CALCULATE MORE ACCURATELY THE NET FLUX OF CARBON INTO THE OCEAN

PROGRAM RESULTS AND BENEFITS

- A RELATIVELY INEXPENSIVE MEANS OF PROVIDING HIGHLY USEFUL INFORMATION ON YEARLY, SEASONAL AND REGIONAL ATMOSPHERIC AND OCEANIC PROCESSES

- IMPROVED AIR-OCEAN CARBON EXCHANGE MODEL

- ADDITIONAL INFORMATION ON BOTH ATMOSPHERIC AND OCEANIC CIRCULATION PATTERNS

- REPORTS FROM EXXON ON THE FINDINGS ISSUED JOINTLY WITH LAMONT-DOHERTY AND OTHER PARTICIPATING INSTITUTIONS

- SAMPLING VESSELS WILL BE AVAILABLE FOR ADDITIONAL SCIENTIFIC MEASUREMENTS TO ENHANCE OUR UNDERSTANDING OF THE CARBON BUDGET OR RELATED AREAS

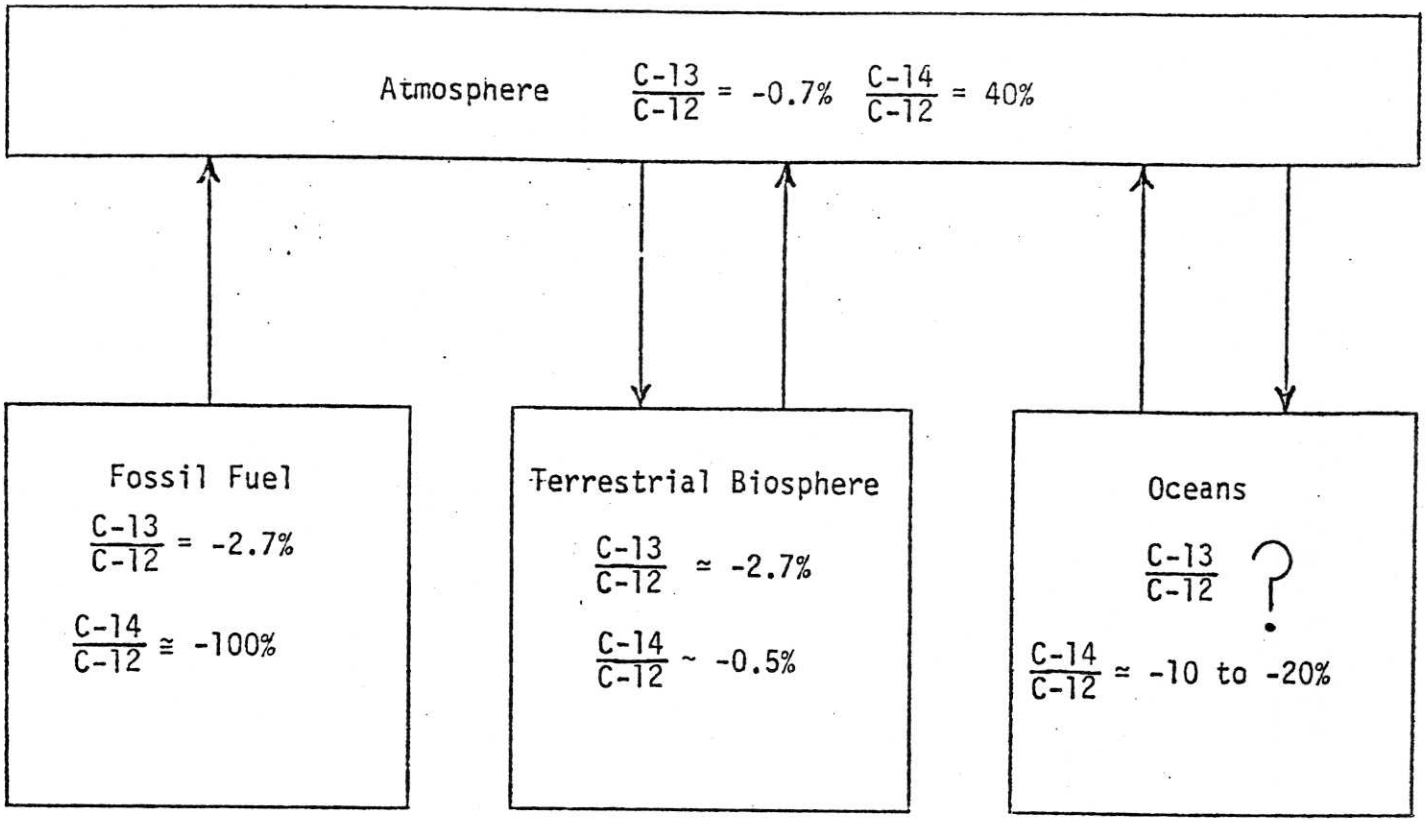
THEORY OF LAND BIOTA SAMPLING

- INCREASE IN ATMOSPHERIC CO_2 MAY BE DUE TO FOSSIL FUEL COMBUSTION OR FOREST CLEARING

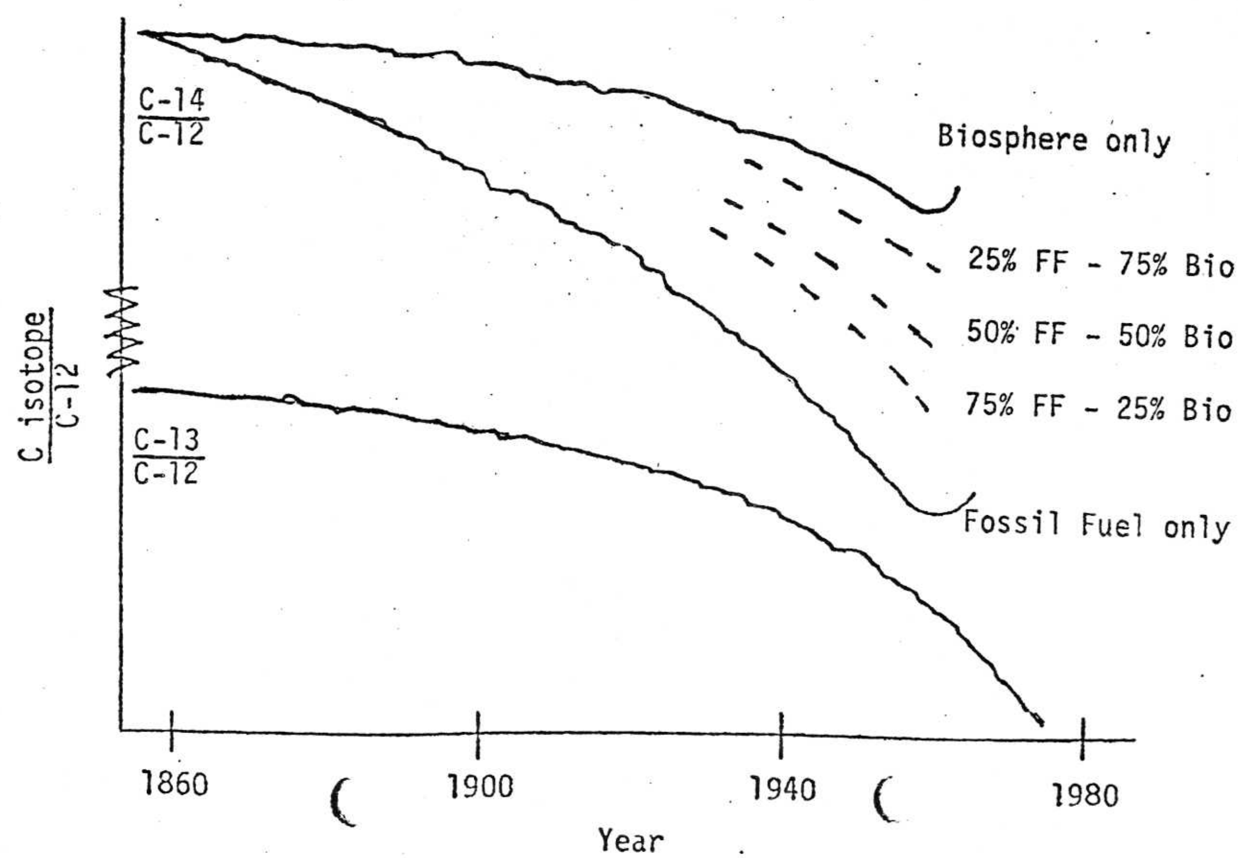
- SOURCE OF CO_2 MAY BE IDENTIFIED BY CARBON ISOTOPES IN THE ATMOSPHERE
  - C-13 IS PRESENT IN FOSSIL FUELS AND PLANTS
  - C-14 IS PRESENT ONLY IN PLANTS

- MEASURING RELATIVE CHANGE OF C-13 AND C-14 IN STORED BIOMASS CAN YIELD INFORMATION ON THE SOURCE OF THE CO_2 THAT WAS PRESENT DURING PLANT GROWTH

Global Carbon Isotope Distribution



Atmospheric Carbon Isotope Ratios



PROPOSED PROGRAM - LAND BIOTA SAMPLING

- TREE RINGS HAVE PROVIDED INITIAL C-13/C-12 AND C-14/C-12 DATA
  - SAMPLE NOT ISOLATED IN YEARLY INCREMENTS
  - NO TEMPERATURE AND GROWTH HISTORY

- USE A LAND BIOTA SOURCE THAT HAS:
  - WEATHER AND GROWTH HISTORY
  - NOT UNDERGONE ISOTOPE EXCHANGE AFTER GROWING SEASON
  - AVAILABLE SAMPLES DATING BACK TO 1830
  - AFTER SOME INITIAL INVESTIGATION, WINE SEEMS TO BE CAPABLE OF PROVIDING THE BEST SAMPLES

PROPOSED PROGRAM SCHEDULE

PHASE I (ONE-YEAR PROGRAM - K$ 300 EXXON AND K$ 200 DOE)

- ESTABLISH COOPERATIVE PROGRAM WITH LAMONT-DOHERTY
- INITIATE RESEARCH WITH A SINGLE TANKER AS A PILOT PROGRAM
- IMPLEMENT DRILLING SHIP SAMPLING PROGRAM
- CARRY OUT WINE MEASUREMENT PROGRAM FOR ONE LOCATION

PROPOSED PROGRAM SCHEDULE (CONTINUED)

PHASE II (FIVE-YEAR PROGRAM)

- IMPLEMENT FULL-SCALE TANKER PROGRAM USING UP TO FIVE DIFFERENT ROUTES (~ M$/A 1.4 - GOVERNMENT)
- CONTINUE DRILLING SHIP PROGRAM AT SUITABLE LOCATIONS (K$/A 50 - EXXON)
- CONTINUE LAND BIOTA MEASUREMENT WITH GEOGRAPHICALLY DIFFERENT SOURCES (K$/A 80 - EXXON)

ESTIMATED COST OF FULL PROGRAM

(1979 K$)

	PHASE	1979	1980	1981	1982	1983	1984
DRILLING SHIPS	I	50	--	--	--	--	--
	II	--	50	50	50	50	50
LAND BIOTA MEASURE-MENTS	I	75	--	--	--	--	--
	II	--	80	80	--	--	--
TANKER (PILOT PROGRAM)	I	375	--	--	--	--	--
TANKERS (4 ADDITIONAL)	II	--	1040	1600	1400	1400	1400
TOTAL		500	1170	1730	1450	1450	1450
CUMULATIVE		500	1670	3400	4850	6300	7750
PROFESSIONALS		1.3	3.6	5.6	5.3	5.3	5.3
N-PROFESSIONALS		2.5	7.1	11.8	11.8	11.8	11.8

GREENHOUSE EFFECT

		Funding		Staffing	
		$	Source	GRL	Other Units
1.	Develop background	20 k	ER&E	1 P	
2.	Develop research program	30 k	ER&E	1 P	
3.	Obtain ER&E management approval	-		1 P	
4.	Advise Exxon Corp. & affiliates	5 k	ER&E	1 P	
5.	Advise DOE of program	-		1 P	
6.	Plan program with affiliates (Exxon International, EUSA, etc.)	5 k	ER&E	1 P	
7.	Arrange university partnership	50 k	ER&E	1 P	
8.	Designate program manager	-	-	-	-
9.	Order and assemble instrumentation	125 k	ER&E	1 P	
0.	Begin Phase I			1.3 P	
	- Tanker No. 1	275 k	ER&E		
	- Drilling Ship	25 k	ER&E		
	- Land biota measurements	75 k	ER&E		
1.	Prepare and submit proposals to DOE	30 k	ER&E	1 P	
2.	Publish initial results	30 k	ER&E		
3.	Order additional equipment	425 k	DOE		
4.	Begin Phase II			6 P	
	- 5 tankers	6.8 M	DOE		
	- 9 drilling ships	225 k	ER&E		
	- 2 different land biota sources	160 k	ER&E		
5.	Awareness and corporate dissemination of information on overall problem	70 k	ER&E	0.1 P