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ENERGY FROM MARINE BIOMASS

Final Report

By
Alan N. Tompkins

March 20, 1979

Work Performed Under Contract No. ET-78-F-03-2165

General Electric Company
Re-entry & Environmental Systems Division
Philadelphia, Pennsylvania

U.S. Department of Energy

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GENERAL ELECTRIC COMPANY
RE-ENTRY & ENVIRONMENTAL SYSTEMS DIVISION
3198 CHESTNUT STREET, PHILADELPHIA, PENNA. 19101

PREPARED FOR

U.S. DEPARTMENT OF ENERGY
FUELS FROM BIOMASS BRANCH
SOLAR TECHNOLOGY

UNDER COOPERATIVE AGREEMENT ET-78-F03-2165

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TITLE

EXECUTIVE SUMMARY

The key product of the Cooperative Agreement effected in 1978 between the Department of Energy and the General Electric Company has been the fabrication, assembly and successful deployment of the first open ocean, deep water Biological Test Farm related to the continuing search for alternate energy sources. This Farm is dedicated to the study of the growth and nutrition of Macrocystis pyrifera (Giant California Kelp) with the far reaching goal of commercializing an ocean grown biomass feedstock for production of substitute natural gas (SNG). Several unique engineering challenges have been successfully attached, not the least of which was the innovative fabrication and vertical deployment of a 1,500 foot long, 24 inch diameter flexible pipe for the upwelling of nutrient rich bottom water to the Test Farm. The application of this engineering "first" relates not only to the Marine Biomass Program but to other deep water oceans' programs, i.e. OTEC.

Supporting research sponsored by DOE under the terms of the 1978 Cooperative Agreement included the continuation of efforts to develop an optimized marine derived anaerobic culture for the conversion of kelp to methane gas. The successes of this research during 1978 continue to hold promise of maximizing the anaerobic conversion/methane generation process to the theoretical yield limits using marine strains compatible with kelp in the aquatic habitat and with the attendant environmental constraints of the digester. To this end, this research has shown that high salt concentrations, up to 7% can be accommodated, ambient temperature digestion can proceed with no apparent loss in gas production as opposed to the classic mesophilic (37° C) processes, and the key kelp constituents, mannitol and algin, are completely utilizable and theoretically convertible to methane.

A "Gas Cost Analysis" was conducted in 1978 as part of the on-going Systems Requirements and Economic Analysis task. This task is designed as a key program tool for coordinating and guiding the experimental and analytical work performed on the Marine Biomass Program. The first-order results of the "Gas Cost Analysis" indicate that the Marine Biomass SNG costs will be competitive with other SNG sources falling in the range of $3 to $6 per million BTU. The cost could even be less when credits for by-products, such as fertilizer or co-products such as fish and shellfish are included.

PROGRAM STATUS

A. PROGRAM SUMMARY

B. MAJOR ACHIEVEMENTS

C. PROBLEMS AND SOLUTIONS

PROGRAM STATUS

A. PROGRAM SUMMARY

During 1978, the Energy from Marine Biomass Program proceeded along two major development paths. These were:

(1) The construction, deployment, and start-up of a Biological Test Farm to be used by the California Institute of Technology for conducting growth rate and productivity experiments on adult kelp plants.

(2) The continuation of experimental work in gas generation research.

The major milestone for the program for 1978 was the construction, deployment and start-up of the Biological Test Farm. Global Marine Development Inc. of Newport Beach, California was the contractor for this part of the program. During the first six months of 1978, the final design of the Test Farm was completed as well as fabrication and assembly plans, and deployment procedures.

The Test Farm is comprised of four major subassemblies. The first is the mooring system designed to hold the system in place in its proper position five miles off Laguna Beach, California in 1800' of water. The mooring system includes three (3) identical 16' diameter buoys each of which is connected a 15,000# anchor set at the vertices of an equilateral triangle 550' on a side. The main structural element of the system is the machinery buoy and substrate. The machinery buoy contains the diesel engines and pumps for bringing water up to the surface from a depth of 1500'. The machinery buoy supports a substrate which provides the lines for holding up to 100 adult kelp plants such that the kelp plant holdfasts are approximately 60 feet below the surface of the water. The total machinery buoy/substrate assembly has a dry weight of 110,000 pounds. The third and most technically challenging part of the system is the upwelling pipe. The upwelling pipe was sized to draw 8,900 GPM of water from a depth of 1500' containing nitrogen in the form of nitrates and nitrites at the pump discharge in a concentration of 25 microgram atoms/per liter of water. The material selected for the pipe was polyethylene, manufactured by DuPont under the trade name of Sclairpipe. The pipe is 1465' long and 2' in diameter and was fabricated from 60' sections by fusing them into one continuous element. Sclairpipe has previously been used in marine applications for sewer outfalls and water lines by laying the pipe on the floor of the ocean or lake. As part of the farm, the pipe is held vertically by the machinery buoy, similar to the application required for OTEC. Because of this similarity between applications, the National Oceanic and Atmospheric Administration participated in the program by providing instrumentation on the upwelling pipe to monitor strains induced in it during deployment.

The remaining major assembly of the Test Farm is the current retardant curtain. The curtain was designed to act as a barrier around the machinery buoy to reduce surface currents of .5 knots or less to .1 knot thereby allowing nutrients brought to the surface by the upwelling pumping system to be retained longer in the vicinity of the kelp plants. The curtain was made of nylon reinforced vinyl in panels 39 feet wide and 35 feet deep. These were connected directly to the mooring system, and designed to lift up at currents of .5 knots or greater, thereby limiting the load on the mooring system.

Construction of the Test Farm started in Long Beach, California on June 2nd and was completed on September 13th. Fabrication and assembly of the machinery buoy and substrate were provided by the Bethlehem Steel Company's San Pedro Shipyard. The upwelling pipe fabrication was performed by DuPont. The mooring system was also assembled by Bethlehem Steel prior to deployment.

Deployment at sea started with the mooring system in the last week of August. The machinery buoy/substrate assembly were deployed uneventfully on September 14th. The first pipe deployment was attempted on September 19th but was aborted due to inclement weather. A second and successful attempt was made during the week of September 24th.

Though the general health of kelp plants in the coastal areas was poor, the accumulation of plants for use on the Test Farm began on October 2nd and continued through October and November while Test Farm mechanical shakedown and debugging were in progress. During the first week of December, 100 adult plants were transferred from shallow waters near shore where they had been stored to the Test Farm. One-half of the curtain was then installed, and a period of observation and data collection was begun including weekly measurements of growth of juvenile fronds, analysis of dissolved nutrients in water samples and blade tissue analysis.

Initial observations of curtain performance by underwater photography provided clear evidence of the effectiveness of the curtain in reducing currents. Measurements of nitrates/nitrites in the upwelling system discharge varied from 25 to 32 microgram atoms/per liter of nitrogen as determined from five weekly measurements during December 6th to January 2, 1979. Storms during December began tearing the curtain at its points of support, and by the end of the month, most of the curtain was lost. The effect of the loss of the curtain combined with intense storm induced currents and waves and resulting motions of the farm, was abrasion of many of the plants against the Test Farm structure.

Action is underway as part of the 1979 program to select a stronger curtain material and to change the curtain assembly and support design. In order to provide additional protection for the plants, the curtain design will also be changed so that it will lift up at currents higher than .5 knots. The intensity of the storms began increasing during January, causing further attrition such that by month's end, the useful population was reduced to eighteen plants. By the first week of February, there were no viable transplants left on the farm.

A period of hardware repair and modification, and curtain redesign and reinstallation is now underway taking advantage of the lessons learned during the first two months of operation. It is planned that after the stormy season has subsided and after the redesigned curtain has been installed, that the farm will be replanted with as healthy as plants as can be obtained. These will be taken directly from natural beds to the Test Farm.

PROGRAM STATUS

During 1978, gas generation experiments have been conducted at the General Electric Company, the United States Department of Agriculture, and the Institute of Gas Technology. The research conducted at General Electric was supported by the Department of Energy under terms of the Cooperative Agreement. The work at the Institute of Gas Technology and the United States Department of Agriculture was supported by other outside research funds.

The research at General Electric is directed to the development of an optimized marine inoculum, as an alternative to sewage derived inoculum, for potential incorporation into the total gas generation process development research being conducted at the Institute of Gas Technology. The potential results of this research could have major impact on several significant cost centers in the gas generation process. Tests on enriched anaerobic cultures composed of marine microorganisms have indicated that such inocula can be incubated at ambient temperatures, rather than at the usual 35° C digestion temperatures without sacrificing reaction rate. This research has also identified:

Optimum pH values for maximum enzymatic degradation of major kelp constituents;

Specific enzyme requirements for degradation of each major constituent of kelp;

A number of inhibiting bacteria in mixed inocula which, if removed, will allow significant increases in methane yield under selected culture conditions;

Marine microorganism enrichments which can produce methane from the kelp constituents: algin, cellulose, mannitol and fucoidan.

The work at the U.S. Department of Agriculture has identified pretreatment/posttreatment process steps which may increase the bacterial digestibility of kelp. Data on energy consumption and cost data have been developed on pretreatment processes such as single and multi-stage grinding and kelp pressing. Baseline pretreatment processes and process equipment have been evaluated, and a material balance for the selected process stream has been provided.

Additional studies related to this task have identified the potential of the digester solid effluent as an animal feed supplement. The data from these investigations indicate that the anaerobic digestion process effluent will result in a feed supplement that chemically is comparable in protein value to soy protein and may in fact exceed the nutrient value of any protein in terms of its amino acid composition.

PROGRAM STATUS

The work at the Institute of Gas Technology in 1978 has been directed to the definition and optimization of the total anaerobic digestion process for conversion of kelp to methane. The results of this task to date include the laboratory demonstration of stable, reproducible methane production from raw kelp by an inoculum which has been adapted for kelp digestion. This was done by the development of baseline inocula and detailed experimental investigations of the physicochemical and biochemical parameters that would maximize methane yield and process efficiency. Basic information on kelp digestion kinetics has been developed. Digesters have been stabilized at a loading rate of 0.2 lb VS/ft^3 and 10 days retention time, improved over the values of 0.1 lb VS/ft^3 and 18 days respectively seen in 1977.

This research has further shown that:

Kelp is degradable in saline culture and can be fed directly to digesters and digested effectively;

Kelp digestion reaction rate is insensitive to drastic reductions in particle size;

Current methane yields per lb of VS on the average, exceed those of any other known biomass form reported to date (approximately 71% of that theoretically attainable);

The addition of supplementary nutrients to the reactor is not necessary.

PROGRAM STATUS

B. MAJOR ACHIEVEMENTS

Test Farm

1. The test farm upwelling system has performed as designed providing 9000 gpm of water containing from 25 to 32 microgram atoms per liter of nitrogen in the form of nitrates and nitrites.

2. The test farm's mechanical structure has performed as designed, and the integrity of the test farm's mechanical structure continues to be sound.

3. The curtain, as a device to reduce currents in the immediate vicinity of the plants and thereby protect the plants and collect nutrients works as evidenced by photographic coverage showing the kelp canopy on the surface of the water and in a vertical attitude in a .4 - .5 knot current.

PROGRAM STATUS

Gas Generation Research

1. Digestion has been conducted at ambient temperature with marine derived inocula, at the liter scale, with no loss in gas production.

2. Digestion has been conducted at salt concentration of up to 7% (seawater is 3%), at the 10 liter scale using sewage derived inocula.

3. Based on the published literature, the methane yield from the anaerobic digestion of kelp is higher than for other types of biomass.

4. Ground, undiluted, raw kelp can be added directly to the digesters.

C. Problems and Solutions

1. The curtain is being changed as part of the 1979 program to increase its ability to survive storms since the curtain was destroyed by two storms. The curtain must also provide "plant protection" function to reduce plant abrasion as well as nutrient containment.

2. The operation of Engine #1 in the upwelling pumping system has been unsatisfactory. Action is underway to replace the engine under the manufacturer's warranty.

3. The Test Farm must be replanted in 1979 after curtain reinstallation, with healthy plants, obtained directly from natural beds without holding, from the same water depth (60') as the Test Farm substrate.

4. An experiment start-up period of at least three months, after farm planting with healthy plants, is essential before data evaluation can begin.

C. Problems and Solutions (cont'd.)

5. Storm induced waves and currents have resulted in relative motion and contact between the plants and the structure causing abrasion to the plants. Instrumentation must be provided to measure the motions of the Test Farm structural elements.

6. Automatic fail/safe controls in the upwelling pumping system have activated properly thereby turning off the engines as required but resulting in periods of up to five days without upwelling. Continuous monitoring (recording and alarm) of the upwelling pumping system must be provided in order to minimize periods of time without upwelling.

INTRODUCTION

This final report is presented in four discrete sections.

Section I - Ocean Engineering

This section discusses the 1978 efforts toward the design, construction, deployment and operation of the Biological Test Farm. These ocean engineering aspects of the Marine Biomass Program were performed by Global Marine Development Inc. via subcontract and under the direct supervision of the General Electric Company, Re-Entry & Environmental Systems Division.

Section II - Inoculum Development

This section discusses the 1978 efforts directed toward isolating and evaluating marine microbial strains responsible for degradation of kelp and subsequent methane generation, and ultimately reconstituting and controlling those appropriate strains to effect this transformation more completely and efficiently. This work was performed by the General Electric Company, Re-entry & Environmental Systems Division.

Section III - Systems Analysis and Development

This section details the first order economic analysis conducted in 1978 using the available data on farm yields, and processing costs.

This "Gas Cost Analysis" was conducted by the General Electric Company with supporting data provided by the various participants involved in the Marine Biomass Program.

Section IV - Energy from Marine Biomass Project - Photograph Review Test Farm Construction and Deployment

This section consists of photographic coverage of the Test Farm fabrication, deployment and operations.

SECTION I

OCEAN ENGINEERING

DISCUSSION

Final Design:

The objective of the design effort was to provide an open ocean test bed for the cultivation of *Macrocystis*. Test Farm design was completed and was reviewed and approved in March 1978 by GE/RESD.

Test Farm Design Description:

The design of the Test Farm represented several engineering challenges:

- The structure must be open and yielding, rather than rigid, so as not to offer substantial resistance to the ocean currents, winds, and waves.
- The structure must survive a 100 year storm with minimal damage.
- The structure must be completely compatible with the biological requirements for *Macrocystis*.
- Personnel safety and operational reliability were prime design constraints.
- The structure must be moored, for test purposes, in approximately 2000 feet of water.
- Water must be reliably pumped up, or upwelled, from a depth of 1500 feet in order to satisfy the biological requirement of providing ambient levels of 3 μ g-a of nitrogen/liter throughout the farm volume.

The Test Farm was designed to initially support approximately 100 adult *Macrocystis* plants. The bases of the plants are attached to the substrate structure depicted in Figures 1 and 2. This structure maintains the bases of the plants at a depth of approximately 60 feet. The plants grow up to the surface and subsequently form a canopy which floats on the surface. Upright

TEST FARM DETAIL PROFILE

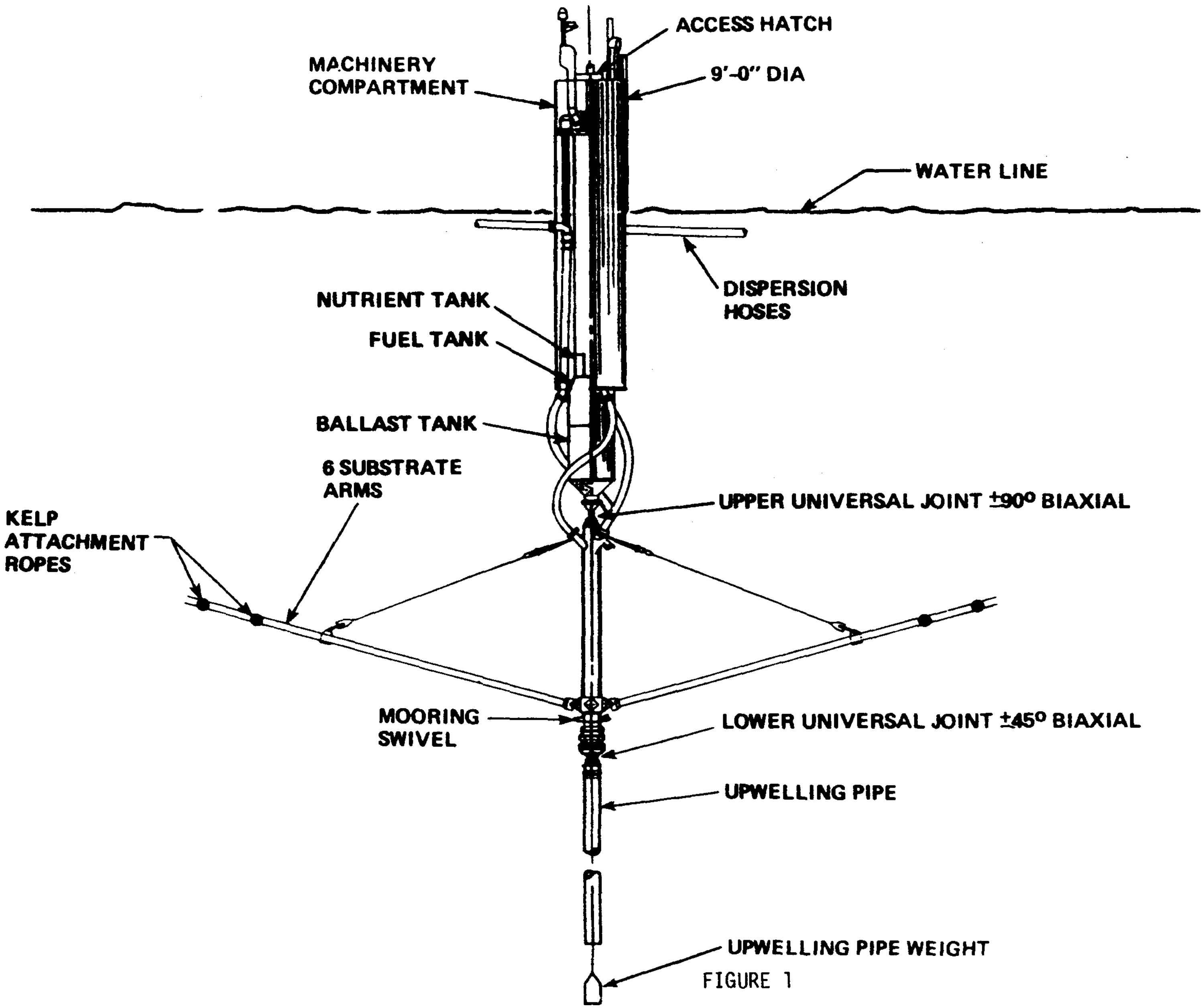


FIGURE 1

TEST FARM PLAN VIEW

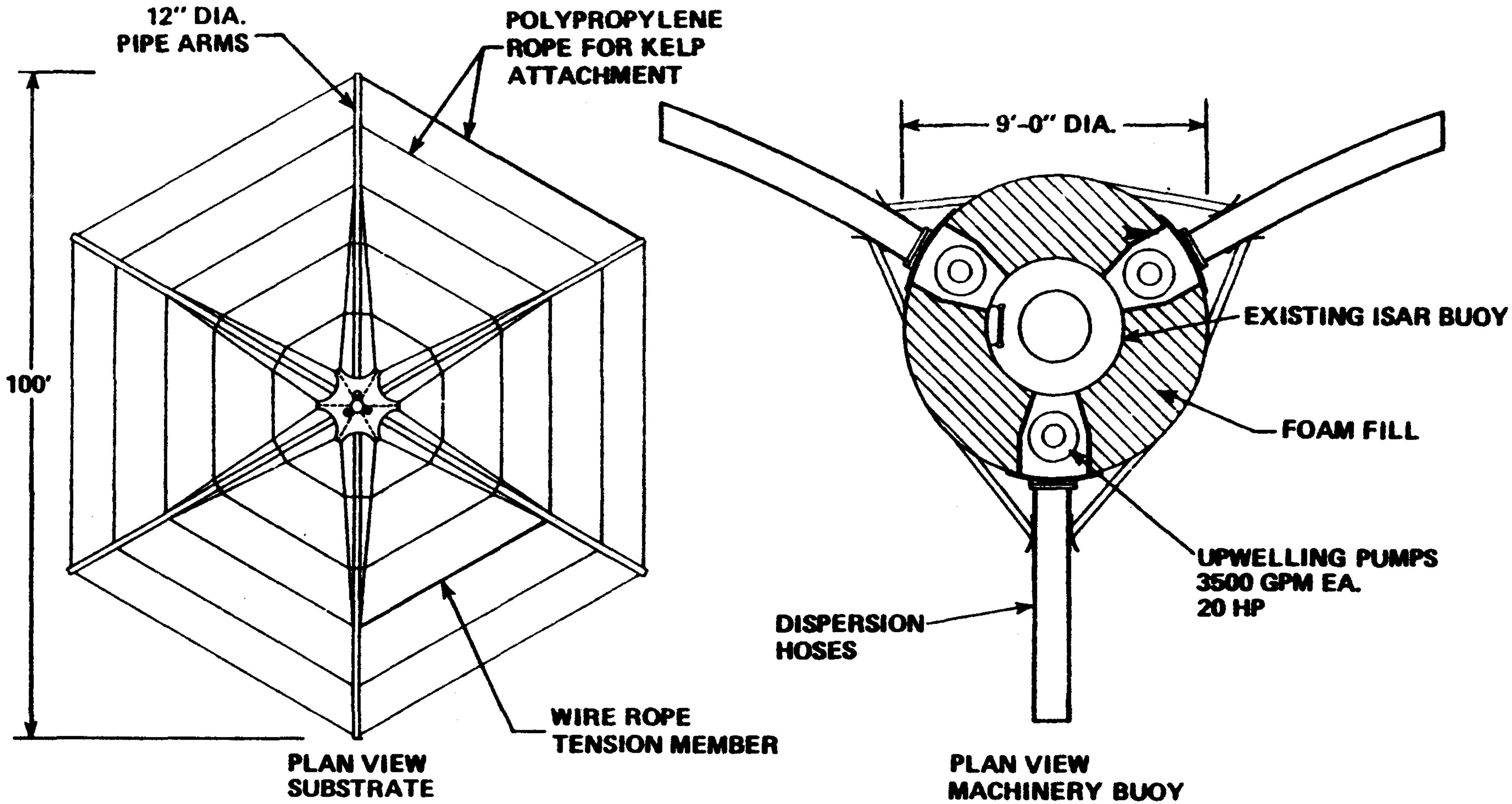


FIGURE 2

growth and floatation result from the presence of specialized, buoyant parts of the plant called pneumatocysts which act as floatation bladders. The Test Farm has the capability for providing upwelled water, from a depth of 1500 feet through a two foot diameter polyethylene pipe. Conventional diesel engines are used for power. Instrumentation, power and pumping systems are contained in the central spar buoy. The spar buoy also contains a supply of fuel for the upwelling pumps, auxiliary batteries for navigation aids and a system for supplying trace quantities of micronutrients to the farm as required The test structure is positioned in water having a depth of 2,000 feet by a three point catenary mooring system. The lower, kelp bearing and upwelling portions of the system are isolated from wave action by providing gimbals between the support buoy and the substrate as well as between the substrate and the upwelling pipe. Analytical calculations, verified by field tests indicated that for a farm of this size, sufficient upwelled water could not be maintained on the farm in the presence of currents in excess of .1 knot. At these current speeds, the current velocity is much greater than the sinking rate of upwelled water. Therefore, the nutrient is effectively swept from the farm. This effect would be much less in a larger or longer farm since the downstream kelp would benefit from the current transported nutrients. The design solution selected was the inclusion of a current "barrier"; a curtain structure which reduces ambient external currents to 0.1 knot or less inside the farm structure. The curtain was designed so that if the ambient current exceeds ~.5 knots, the curtain will be lifted up out of the way and will not impose severe loadings on the mooring system.

Upwelling Pipe Design:

A major design challenge was presented by the structural requirements for the upwelling pipe. In order to satisfy the requirement for maintaining an ambient nitrogen concentration in the farm volume of 3 μ g-atoms/liter in up to .1 knot currents the required upwelling rate, for deep water having a nitrogen concentration of 30 μ g-atoms/liter, was estimated at approximately 9000 gallons/minute. This flow rate is made necessary by the fact that with the small (~100 ft. diameter), round, test structure, the nutrient would be transported out by the current almost as rapidly as it is brought to the surface. In order to attain the flow at reasonable horsepower (~ 45), a two foot diameter upwelling pipe was selected. The pipe length was set at 1500 ft. in order to reach the maximum stable level of nitrogen concentration. (Figure 3) Because of the experimental requirements of the test and the stability of supply concentration in the deeper water, the 1500 ft. depth was selected. Consistent with the design philosophy of minimizing resistance to the ocean environment, the upwelling structure was designed to be attached at the upper end only. In this way, the total farm structure is able to yield, within specified limits, both laterally and axially in response to waves and currents (Figure 4). Computer simulation of the upwelling pipe indicated that wave motion would be transmitted, with minimal damping from the top of the pipe structure to the bottom, thereby setting up large bending moments along its entire length. Several pipe structural materials were evaluated for this application. Concrete was immediately rejected due to weight and structural strength limitations. Steel would have required significant increases in the strength of test farm structural members and would have introduced undesirably high inertial forces in the farm system due to its weight. Aluminum had the desirable low mass and light weight but was rejected primarily on the basis of lead time and cost. The pipe structure study then proceeded with detailed analyses of plastic materials, fiberglass reinforced plastic (FRP) and high density polyethylene (HDP) for this application. The bending moments induced suggested that FRP, due to its

NITROGEN CONCENTRATION-VARIATION WITH DEPTH- AREA NINETEEN - FALL

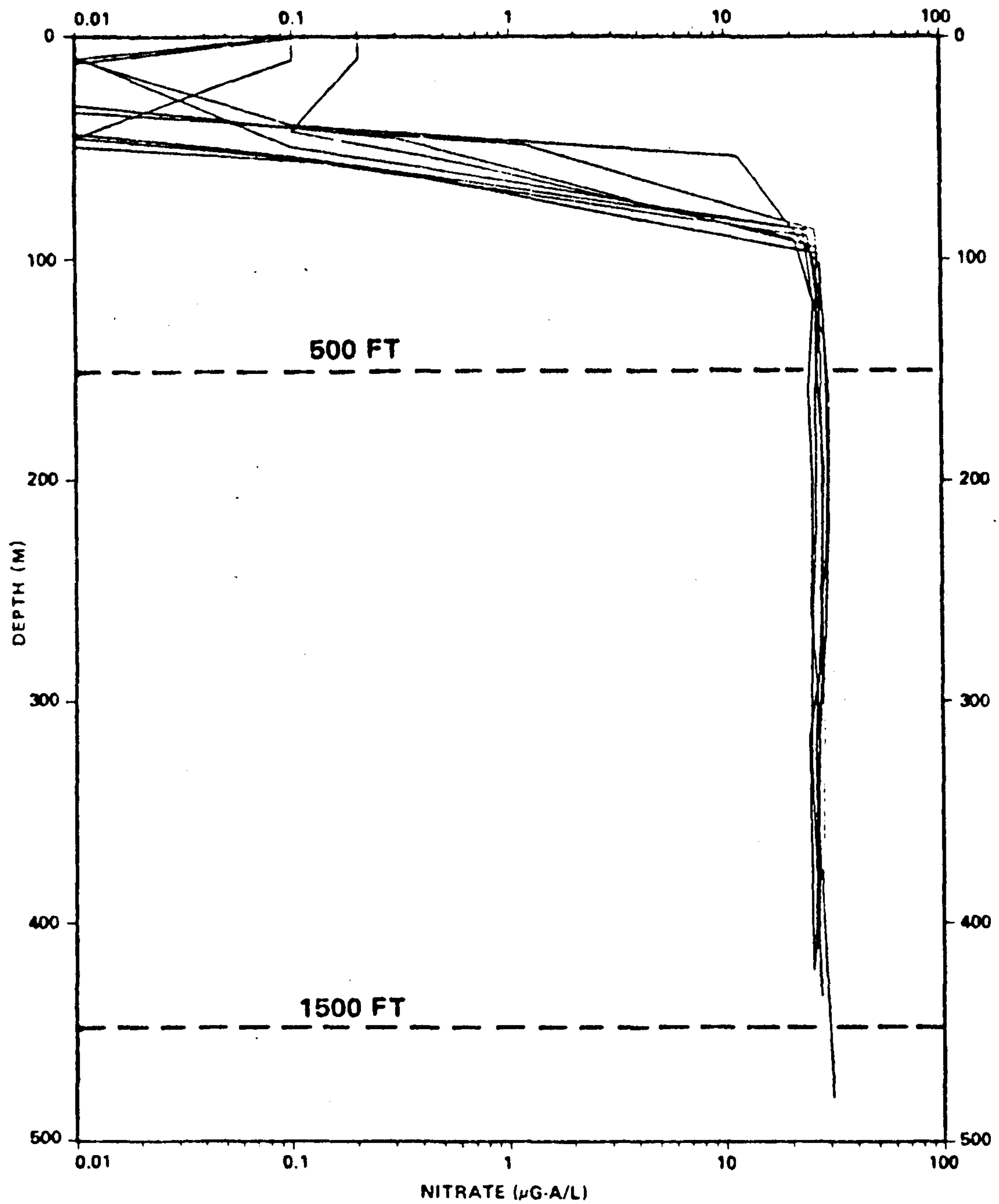


FIGURE 3

TEST FARM GENERAL ARRANGEMENT

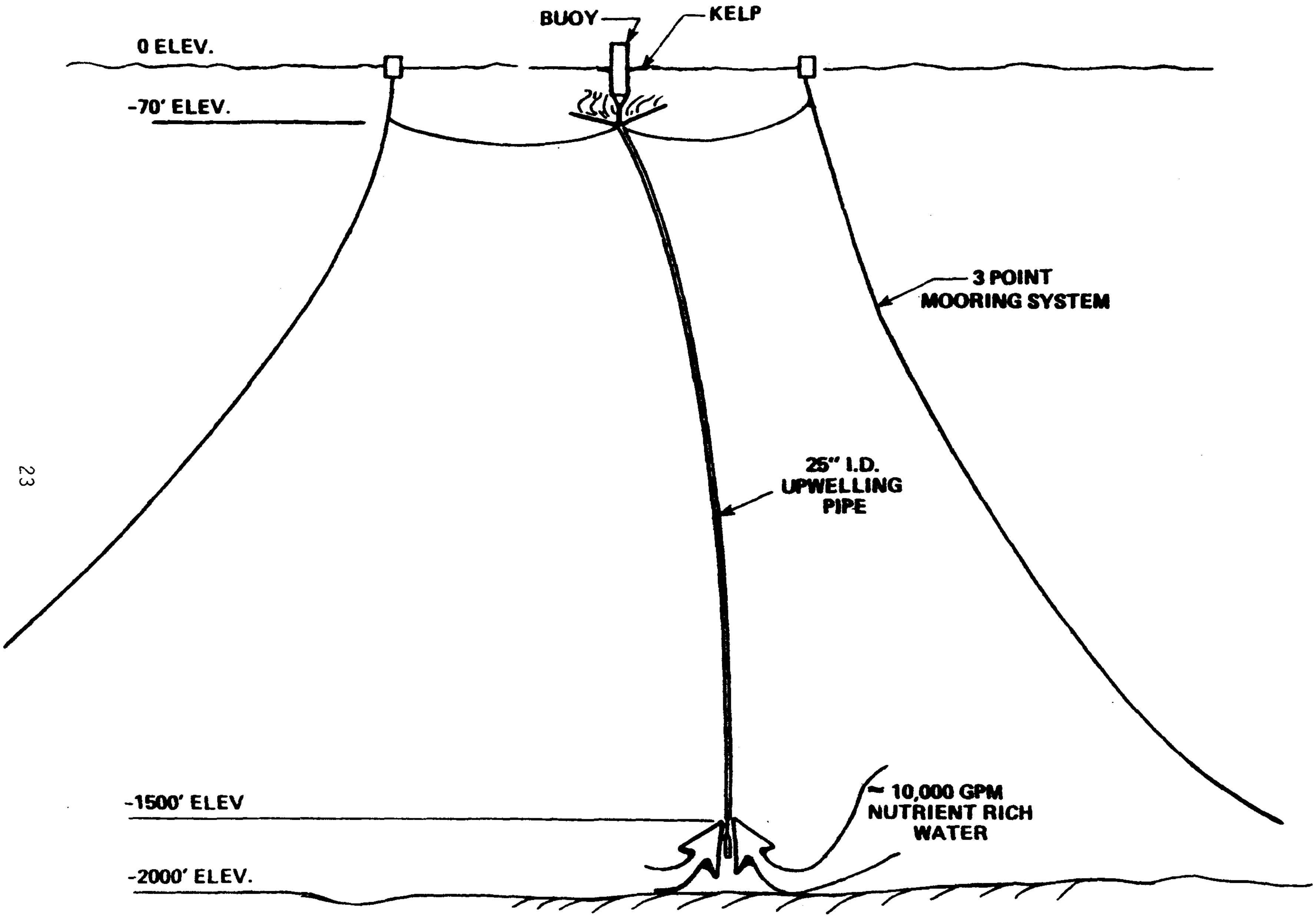


FIGURE 4

stiffness, would be marginal from a structural stress standpoint. In addition, the non-standard fabrication techniques that would be required for this application would introduce excessive manufacturing costs and long lead times. The pipe material selected for this application was HDP. This material is flexible and has very low mass and weight. In fact, since the density is less than one, weight must be added to the structure. Although transmitting the bending moments in the same mode as other materials, the moments were significantly lower than rigid or semi-rigid FRP and well within the structural capabilities of an HDP pipe structure. Figure 5 shows the comparison, by computer simulation, of the effect of pipe stiffness on bending moment. Note that the only acceptable FRP configuration was a completely segmented FRP pipe (Proprietary Global Marine Design). The segmented FRP configuration was rejected because the design was not sufficiently far enough along to meet the procurement and construction schedules of the program. The final HDP pipe configuration is shown in Figure 6.

Test Site Characteristics:

A site survey was conducted, in parallel with the design effort, which investigated several potential locations for the test farm. The farm was installed in an evnironmentally, rather benign area of the Southern California Bight. The site was specifically selected in an area where environmental parameters such as depth, waves, currents, wind, and bottom conditions would be representative of a potential large farm site, but would not reach extreme values that would present undue hardwhips to equipment or personnel during the experiment. Other considerations included the availability of deepwater nutrients and surface temperatures that would be within the required range of *Macrocystis*. Environmental characteristics for the site selected are shown in Table 1.

STIFFNESS EFFECT ON BENDING MOMENT

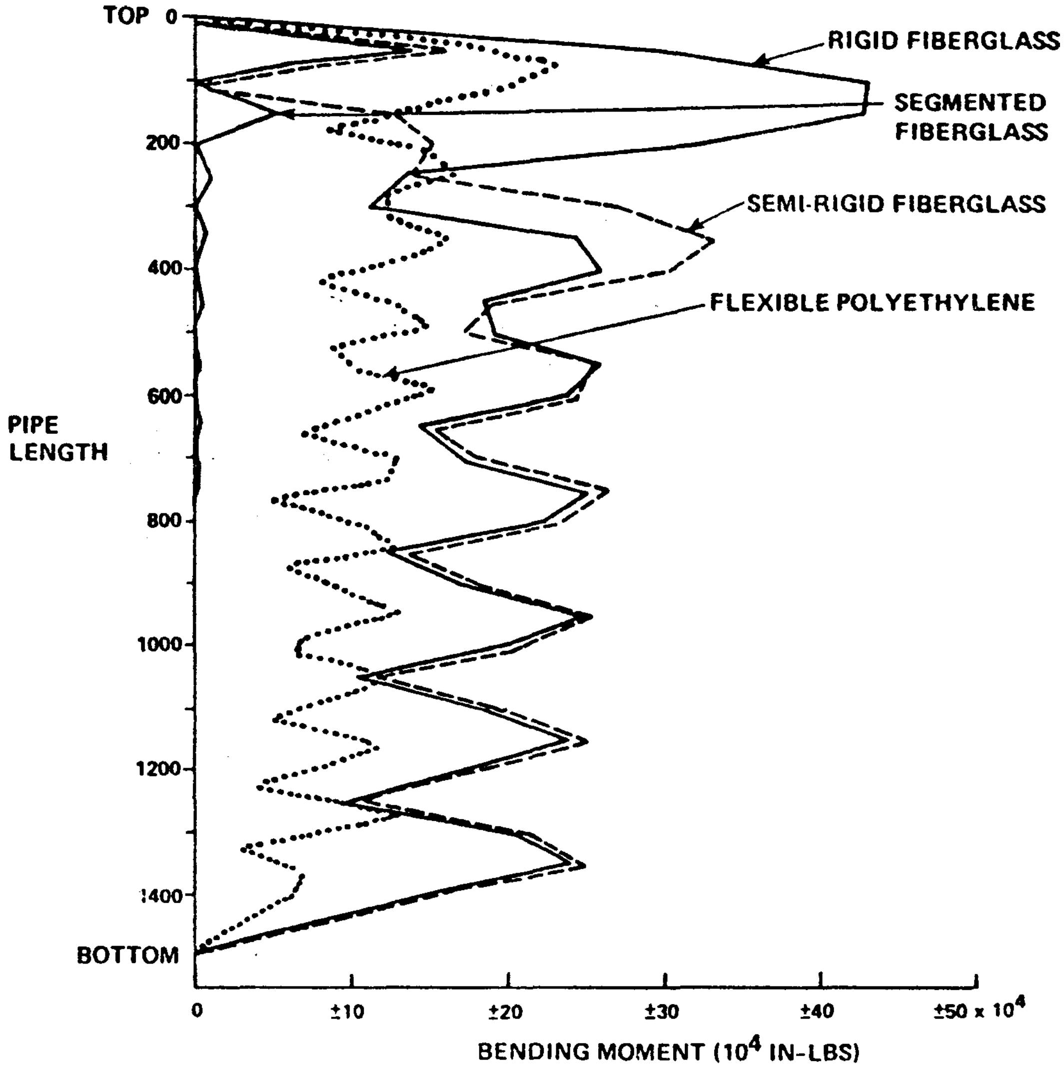


FIGURE 5

UPWELLING PIPE

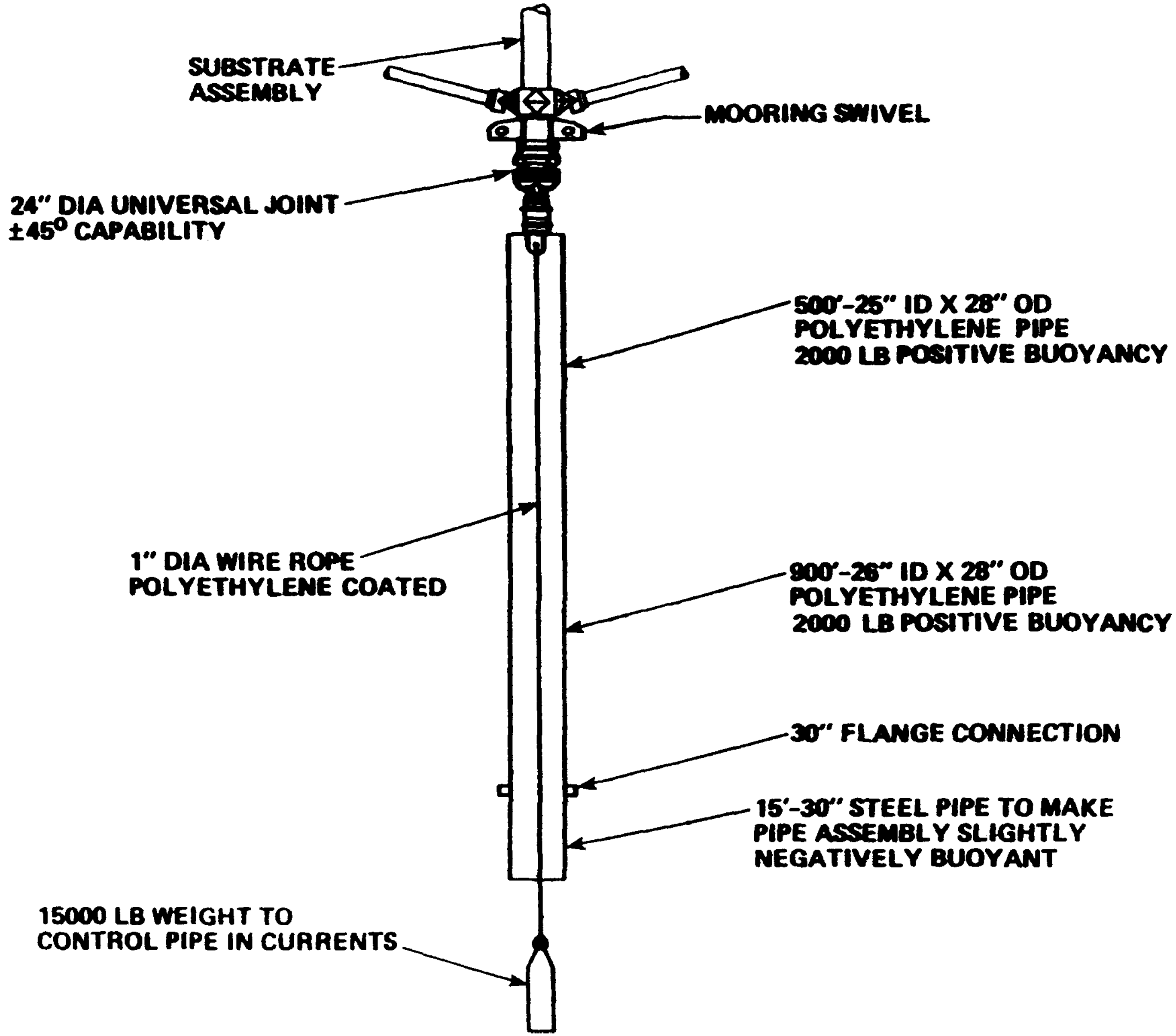


FIGURE 6

TABLE 1

TEST SITE CHARACTERIZATION

Parameter	Average Value
Surface water temperature	20° C or less
Weight height	0.6 M
Wind speed	0.5 - 5 M/Sec.
Current speed (70% of the time)	~0.2 M/Sec.
Max. current speed	0.8 M/Sec.
Wave height for 100 year storm	12 M
Depth	300 - 500 M
NO_3 at 300 M Depth	25 - 30 μg-a/l
Bottom type	Mud - Sandy mud

The test site is located approximately five miles off of Laguna Beach in Southern California.

Design, fabrication, assembly and deployment were performed by Global Marine Development Inc. (GMDI) under the direct supervision of GE/RESD. Suppliers of major test farm elements providing support to GMDI were: Ameron Equipment Division, Southgate, California - buoy fabrication; Bethlehem Steel Corp., San Pedro, California - substrate fabrication and buoy/substrate assembly; DuPont of Canada, Vancouver, British Columbia - pipe fabrication and assembly; Crowley Barge Co., Wilmington, California - buoy/substrate deployment; Offshore Logistics Co. - mooring system deployment; and Submarine Engineering Associates, Newport Beach, California - upwelling pipe deployment.

During fabrication, assembly and deployment, the test farm hardware was treated as three separate subassemblies: Machinery buoy and substrate, upwelling pipe and the mooring system.

The machinery buoy was fabricated at Ameron and then shipped to Bethlehem where it was finished. It was then mated to the substrate structure. The mated subassembly was then carried by barge to the test site. Installation occurred on September 13, 1978.

The mooring system was assembled at Bethlehem Yard and deployed in advance of the machinery buoy on August 21, 1978. After setting the machinery buoy, the upwelling pipe was attached. This occurred on September 13th. Due to weather problems, the first deployment of the pipe was aborted. On September 27, 1978, the pipe was successfully re-deployed and the test farm installation was completed on September 29, 1978. Attachment "A" to this section shows the installation details of the upwelling pipe.

As an adjunct to the main ocean engineering phase of the Marine Biomass Program, an agreement was consummated with the National Oceanic and Atmospheric Administration (NOAA) to obtain data on the behavior of the large polyethylene pipe during ocean operations from the Marine Biomass upwelling pipe installation. This data was of interest to NOAA and DOE for application to the design of the OTEC cold water pipe system. The biomass pipe installation provided a near term and relatively inexpensive opportunity to acquire the "piggy-back" data on a non-interference basis. This adjunct "mini-program" was successfully implemented during the first attempt at pipe deployment. Attachment "B" presents the final report and results of this effort.

Installation of the upwelling pipe was followed by a 30 day period during which final mechanical and electrical testing and minor re-work was performed. On December 12, 1978, the current retardant curtain was installed and the attachment of approximately 100 adult kelp plants was completed. With the accomplishment of these milestones, the experimental observation period was initiated.

SECTION I - ATTACHMENT A

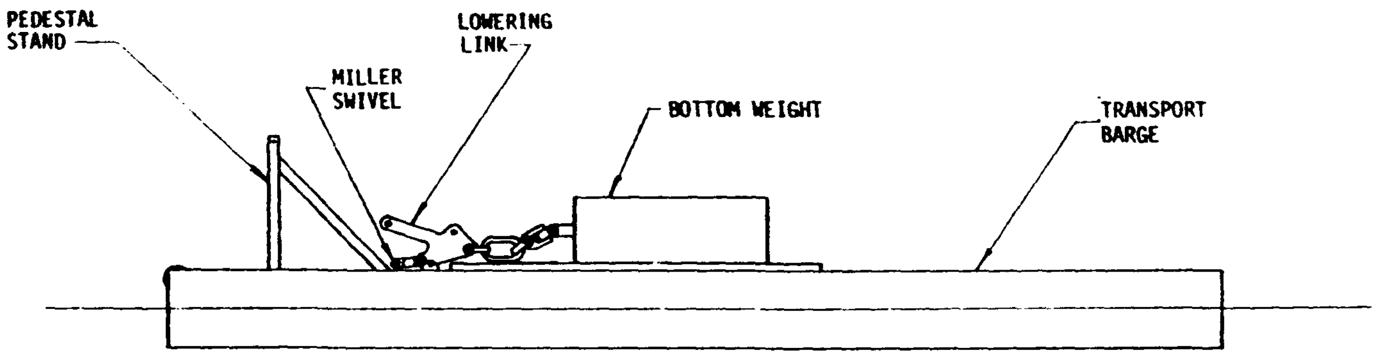
TEST FARM UPWELLING PIPE

FABRICATION

TOWING

UPENDING

INSTALLATION



I <u>NEWPORT BEACH OPERATIONS</u>

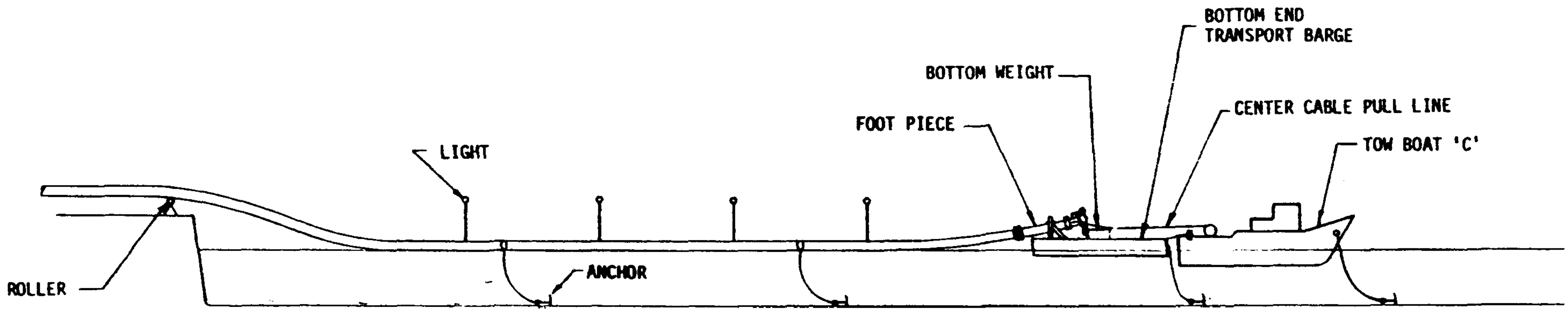
1. TRUCK DELIVERY OF ALL NECESSARY BOTTOM END PARTS WILL BE TO NEWPORT BEACH. PARTS WILL BE ON LOADED TO THE TRANSPORT BARGE AND SET UP. PHOTOS AND SIGN-OFF DONE BY GMDI/GE REPRESENTATIVES.

2. IF FOOT PIECE IS AVAILABLE, A DOCKSIDE LIFTING TEST WILL BE DONE TO VERIFY MECHANICAL LIFTING PROCEDURE AND CORRECT ANY PROBLEM THAT ARISES.

3. AFTER DOCKSIDE TEST, FOOT PIECE IS TRUCK SHIPPED TO DANA POINT.

4. ALL PARTS ARE LASHED DOWN SECURELY TO THE TRANSPORT BARGE AND MADE READY FOR TOWING.

5. THE TRANSPORT BARGE IS TOWED TO DANA POINT BY BOAT 'C' TO BE MATED WITH FOOT PIECE AND SCLAIRPIPE ASSEMBLY.



PIPE ASSEMBLY INSIDE DANA POINT BREAKWATER

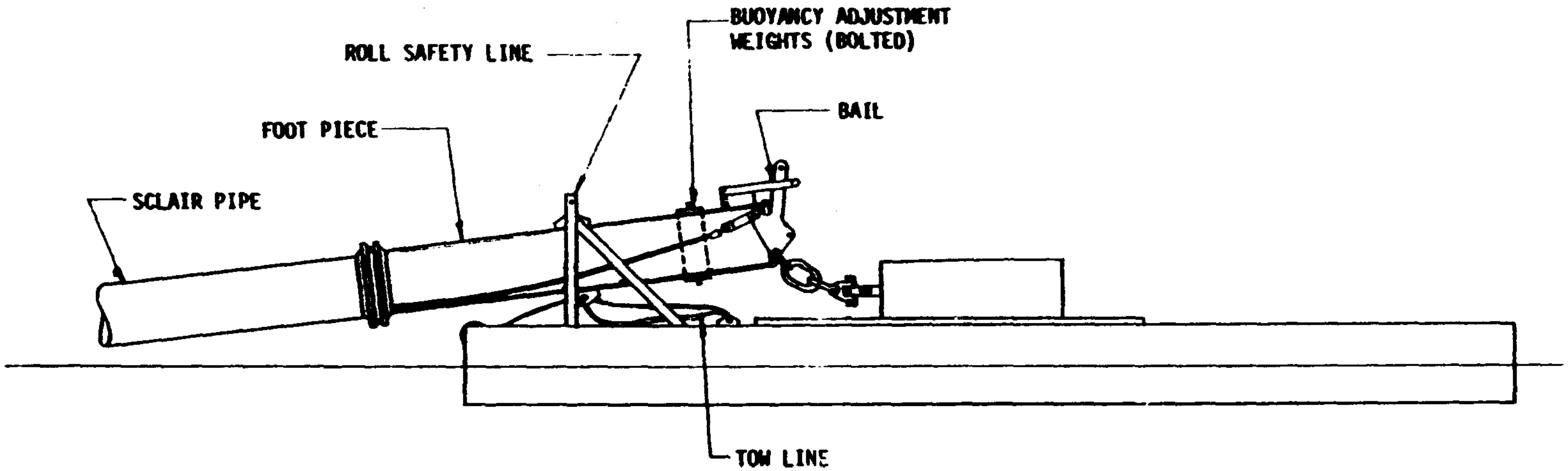
1. WATCHING FOR A GOOD HIGH TIDE WINDOW AND COORDINATING WITH THE BUTT FUSION WELDING OPERATION OF THE SCLAIRPIPE, THE TRANSPORT BARGE WITH BOTTOM WEIGHT AND LINKAGE IS MOORED OFF SEA WALL AND MADE READY BY BOAT 'C' TO HAVE ON LOADED THE FOOT PIECE AND SCLAIRPIPE ASSEMBLY.

2. AS FIRST OF PIPE IS BUTT WELDED, IT IS MADE UP TO FOOT PIECE.

3. A TRUCK CRANE ON THE SEA WALL WILL LOWER OVER THE WALL AND ONTO THE TRANSPORT BARGE, THE FOOT PIECE AND SCLAIRPIPE ASSEMBLY VIA THE TOP MID - PADEYE OF THE FOOT PIECE. BOTTOM END OF PIPE WILL BE PLACED ONTO THE PREVIOUSLY MADE PEDESTAL STAND FOR THE SUPPORT OF THE FOOT PIECE. SAFETY LINES WILL BE USED TO SECURE FOOT PIECE TO THE STAND AT THIS TIME, ALONG WITH A TOWING LINE ATTACHED FROM THE BOTTOM MID-PADEYE TO A PADEYE ON THE BARGE DECK.

4. AS PIPE IS MADE UP, A PULL LINE IS STRUNG THROUGH PIPE TO LATER PULL IN THE CENTER WEIGHT SUPPORT CABLE. TOW BOAT 'C' PULLS BOTTOM END BARGE OUT AS REQUIRED AS PIPE IS MADE UP.

5. PIPE IS KEPT FROM DRIFTING IN HARBOR WITH ANCHORS. ANTI-CHAFFING MATERIAL IS PLACED BETWEEN ANCHOR LINES AND INSTRUMENTATION CABLES.

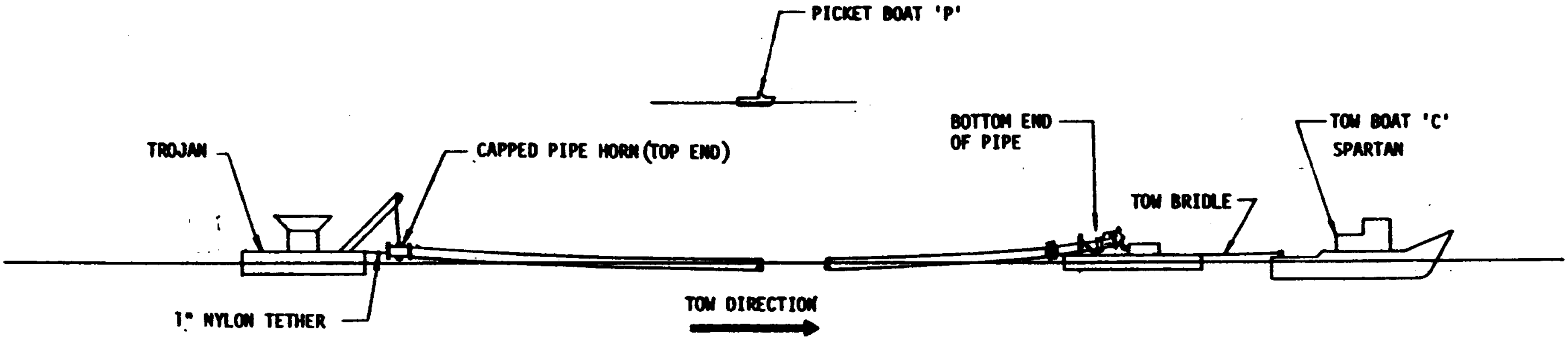


II B. <u>DANA POINT OPERATIONS (CONTINUED)</u>

6. AFTER ALL OF THE UPWELLING PIPE ASSEMBLY IS MADE UP, THE CENTER WEIGHT CABLE IS PULLED THROUGH THE WHOLE PIPE. THE UPPER END OF THE CENTER CABLE IS SECURED TO THE CAP ASSEMBLY AND MADE FAST TO THE HORN ASSEMBLY. THE BOTTOM END SPELTER SOCKET OF THE CENTER CABLE WILL BE CONNECTED AND SECURED VIA COTTER PIN AND WELD TACK TO THE MILLER SWIVEL. THE LINKAGE WILL BE PLACED IN POSITION FOR LATER LIFTING PROCEDURES AND LASHED SECURELY FOR TOWING.

NOTE: CAUTION	ALL CONNECTIONS ARE TO BE MADE BETWEEN THE BOTTOM WEIGHT AND THE FOOT PIECE. TO ALLOW FREEDOM OF MOVEMENT FOR THE FOOT PIECE DURING TOW. SUFFICIENT SLACK IN CENTER CABLE IS REQUIRED.

NOTE:	CHECK POINT - GMDI/GE CHECK & SIGN-OFF OF ATTACHMENT. WITH PHOTOGRAPHS



III PIPE TOWED TO TEST FARM SITE

1. TOP END OF PIPE WITH PIPE HORN IS SUPPORTED ON 'A' FRAME OF TROJAN FOR TOW. PIPE IS TOWED TO SITE, BOTTOM END FORWARD, WITH TOW BOAT 'C' SPARTAN IN CONTROL.

   TROJAN IS TO MAINTAIN CONTROL OF TRAILING (TOP) END WITH INSTRUMENTATION HARNESS LEADS BROUGHT ABOARD. TWO PICKET BOATS ARE EMPLOYED DURING TOWING TO PATROL THE TOW AND PROVIDE TRAFFIC SECURITY.

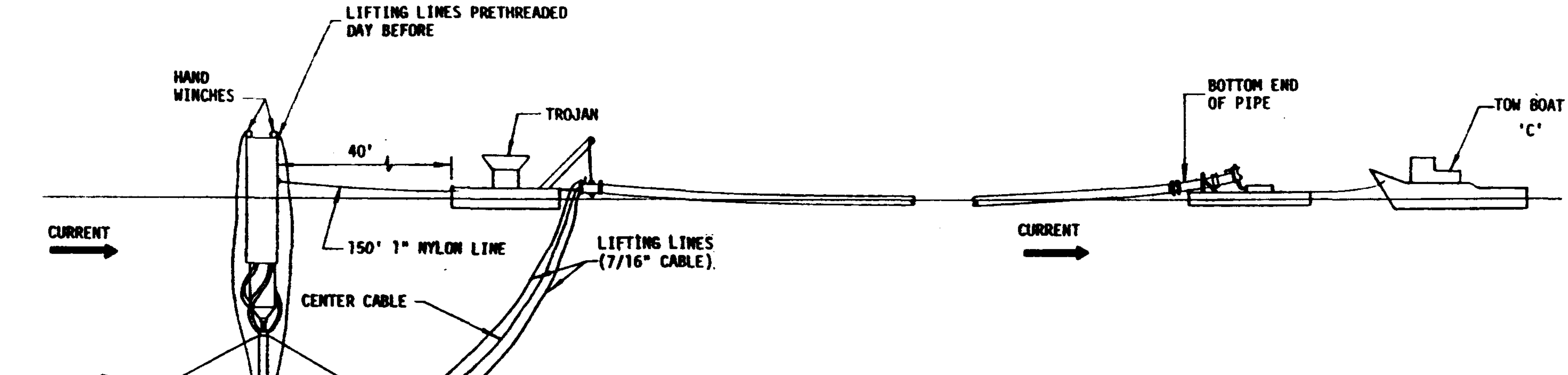
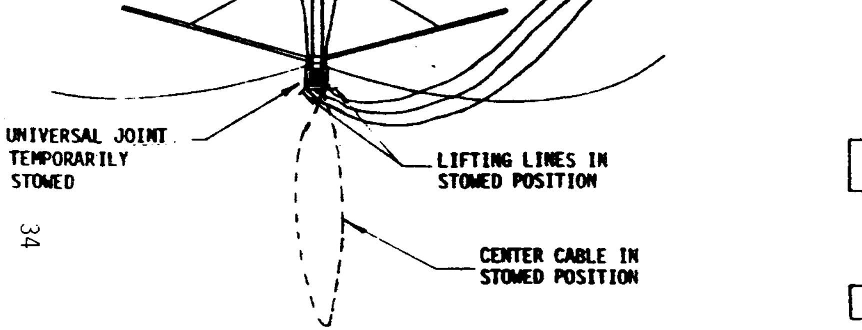
2. TOW BOAT 'C' APPROACHES THE SITE, BUT WELL OUTSIDE OF BUOY'S MOORING SYSTEM ARRAY HEADING DOWNSTREAM. AFTER PASSING SITE, TOW IS STOPPED ABOUT A QUARTER MILE DOWNSTREAM.

NOTE: CARE MUST BE PROVIDED FOR INSTRUMENTATION CABLES AT ALL TIMES

3. TROJAN BACKS TOW TO WITHIN 100' OF SE MOORING BOUY. PICKET BOAT RUNS STERNLINE FROM TROJAN TO THE MOORING BUOY.

4. LET PIPE/BARGE/BOAT 'C' TAKE NATURAL SET WITH WEATHER TO OBSERVE AND DETERMINE FINAL HEADING FOR DEPLOYMENT.

5. BOAT 'C' STAYS STERN TO TO HAVE EFFECTIVE TOWING CONTROL

IV PREPARING TO UPEND PIPE

1. TROJAN VERY SLOWLY BACKS INTO THE MACHINERY BUOY WITH BOAT 'C' CONTROLLING THE BOTTOM END BARGE. TROJAN MOORS STERN END TO MACHINERY BUOY WITH A 150' FOOT LONG NYLON LINE. ALSO PUT OUT LINES TO THE TWO MOORING BUOYS.

NOTE:	CARE MUST BE TAKEN TO INSURE PIPE IS KEPT CLEAR OF KELP FARM MOORING SYSTEM ARRAY THROUGH OUT ALL PROCEDURES.

2. 140 FOOT PART OF CENTER CABLE IS RELEASED FROM TEMPORARY STOWED POSITION BY DIVERS AND HAULED ABOARD THE SIDE DECK OF TROJAN.
3. ATTACH 140 FOOT CENTER CABLE FROM BUOY TO CENTER CABLE FROM INSIDE PIPE.

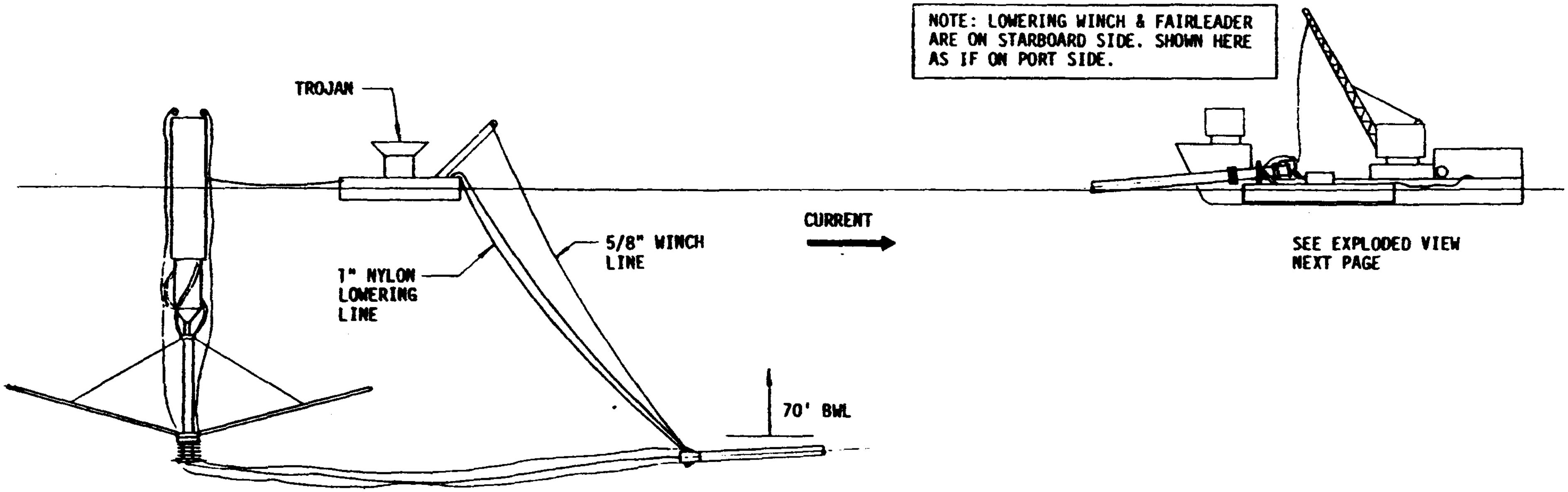
NOTE:	CHECK POINT - GMDI/GE SIGN-OFF AND TAKE PHOTOGRAPHS OF ATTACHMENT

4. 7/16" CABLES FOR LIFTING PIPE (WHICH WERE PREVIOUSLY RIGGED FROM HAND WINCHES ON MACHINERY BUOY WEATHER DECK THROUGH FAIRLEADS AT LOWER UNIVERSAL FLANGES) ARE BROUGHT UP TO TROJAN BY DIVERS AND ATTACHED TO HORN FLANGE. WEATHER DECK ORIGIN OF PIPE TOP END LIFTING LINES ARE TWO TEMPORARILY MOUNTED HAND WINCHES.
5. ATTACH A 300' 1" NYLON LOWERING LINE - DEADENDED ON TROJAN AND THROUGH A SHACKLE ON THE HORN THEN TO THE GYPSY HEAD ON WINCH.
6. ✳ DIVERS MAKE CHECK OF THE LEAD OF ALL WIRES AND SUBSTRATE WIRES.
7. SAMSON MANEUVERS ALONGSIDE BOTTOM END BARGE AND MAKES READY TO LIFT BOTTOM END.

NOTE: CAUTION	DO NOT USE TROJAN PROPELLERS AT ANYTIME WHEN INSTRUMENTATION CABLE IS OVER THE SIDE.

8. SLACK OFF THE TOPE END LOWERING LINES (5/8" WIRE LINE AND NYLON LINE) 70 FEET, SUCH THAT THE TOP OF THE PIPE IS ABOUT LEVEL WITH THE LOWER UNIVERSAL JOINT.

NOTE:	SLACK OFF MOORING ON TROJAN TO INSURE TOP END OF PIPE CLEARS SUBSTRATE.

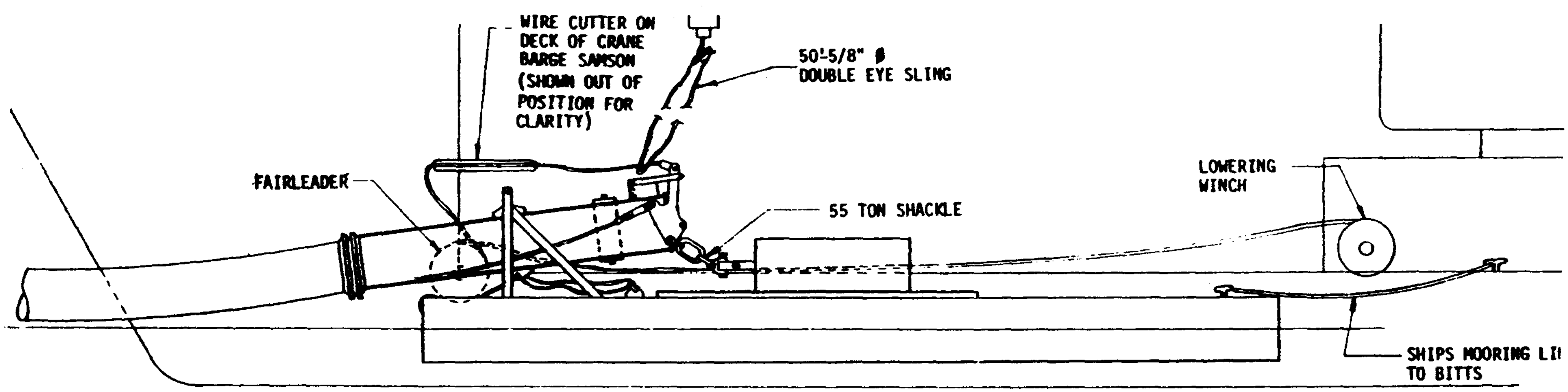


V A. <u>PREPARING TO LIFT ASSEMBLY FROM TRANSPORT BARGE</u>

NOTE: CRANE BARGE SAMSON MUST USE ENGINES TO STAY ALONG SIDE END OF THE BOTTOM END ASSEMBLY BARGE AS CRANE LIFTS THE ASSEMBLY FROM THE BARGE.

1. TOW BOAT 'C' MAINTAINS CONTROL OF BOTTOM END BARGE.

NOTE: IT IS INTENDED THAT THE CRANE BARGE SAMSON KEEP ALONG SIDE THE TRANSPORT BARGE BY THE USE OF HER ENGINES AND NOT WITH MOORING LINES. MOORING TO TRANSPORT BARGE SHOULD BE KEPT SLACK AND ONLY USED TO KEEP THE TRANSPORT BARGE UNDER CONTROL.



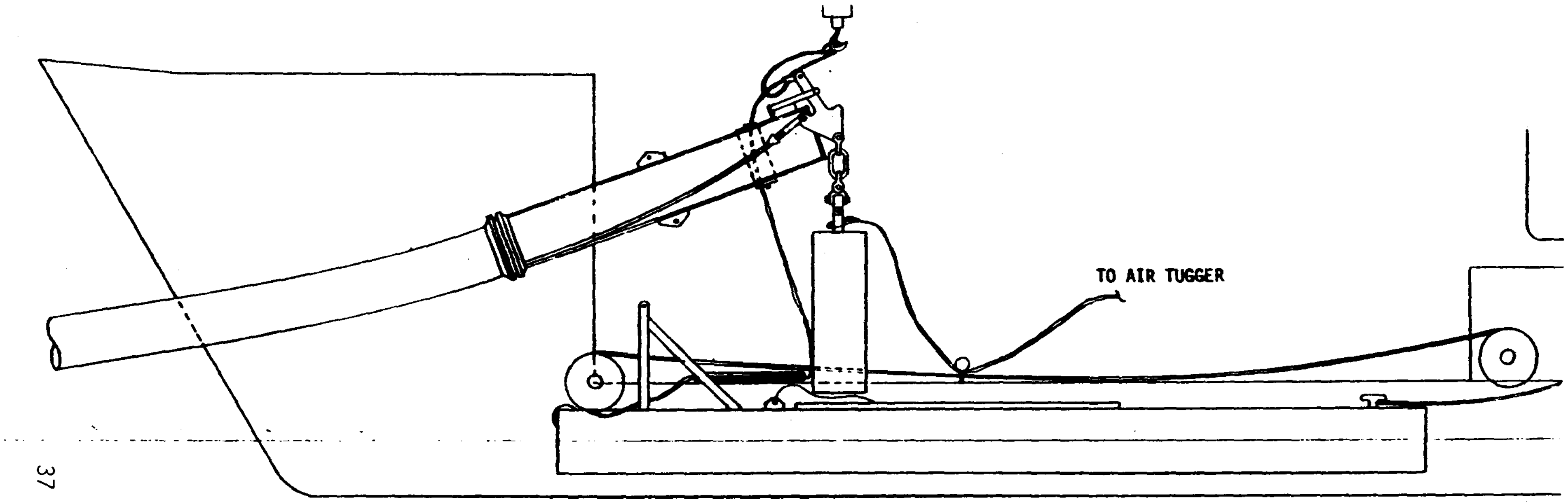
V B. PREPARING TO LIFT ASSEMBLY FROM TRANSPORT BARGE (CONTINUED)

3. RELEASE HOLD DOWNS ON BOTTOM WEIGHT, RELEASE TOWING HOLD DOWNS.

4. THE CRANE BARGE SAMSON LOWERING WINCH 7/8" LINE AND THE BIGHT OF THE 50'-5/8" SLING IS CONNECTED TO THE LONG TONGUE HOLE OF THE LOWERING LINK WHICH IS PASSED THROUGH THE FOOT PIECE BAIL. A LONG LENGTH OF SLACK LINE OF WINCH LOWERING LINE IS LED AROUND THE LOWERING SHEAVE AND ALLOWED TO REST ON DECK OF THE CRANE BARGE SAMSON. SEE DETAIL.

5. THE LOWERING LINE EXPLOSIVE WIRE CUTTER IS PLACED IN POSITION ON THE LOWERING LINE ON THE DECK OF CRANE BARGE SAMSON. THE HANDLING AND POSITIONING OF THIS HARDWARE SHOULD BE COORDINATED WITH THE LIFTING AND LOWERING OF THE FOOT PIECE.

NOTE:	CHECK POINT - GMDI/GE INSPECT RIGGING, SIGN-OFF AND TAKE PHOTOGRAPHS. GMDI MUST GIVE APPROVAL TO PLACE PIPE END IN WATER.



VI LIFTING BOTTOM ASSEMBLY FROM TRANSPORT BARGE

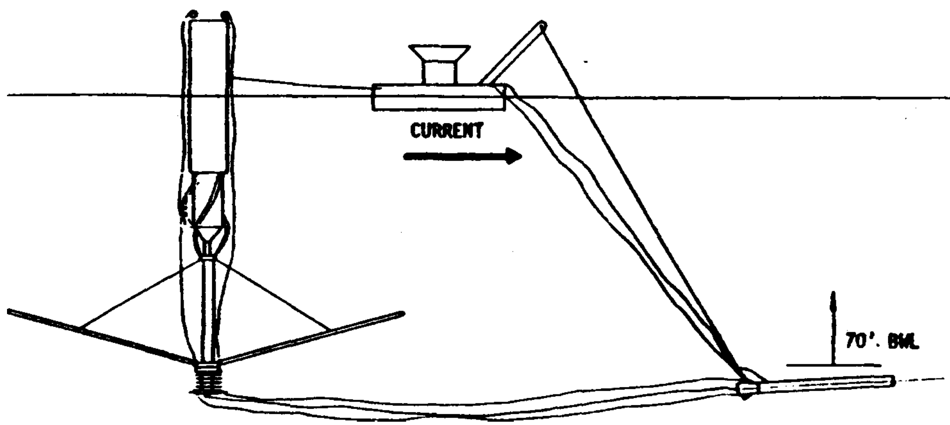
1. THE EYES OF THE SLING ARE PLACED ON THE HOOK AND SUFFICIENT SLACK IN THE SLING TO ACCOUNT FOR RELATIVE MOTIONS OF THE TWO VESSELS. AN AIR TUGGER LINE IS PASSED AROUND THE WEIGHT/LINKAGE AND DEAD ENDED ON THE CRANE BARGE SAMSON. THIS WILL BE USED TO PREVENT SWINGING IN THE TRANSVERSE DIRECTION. NO LIFTING IS DONE YET.

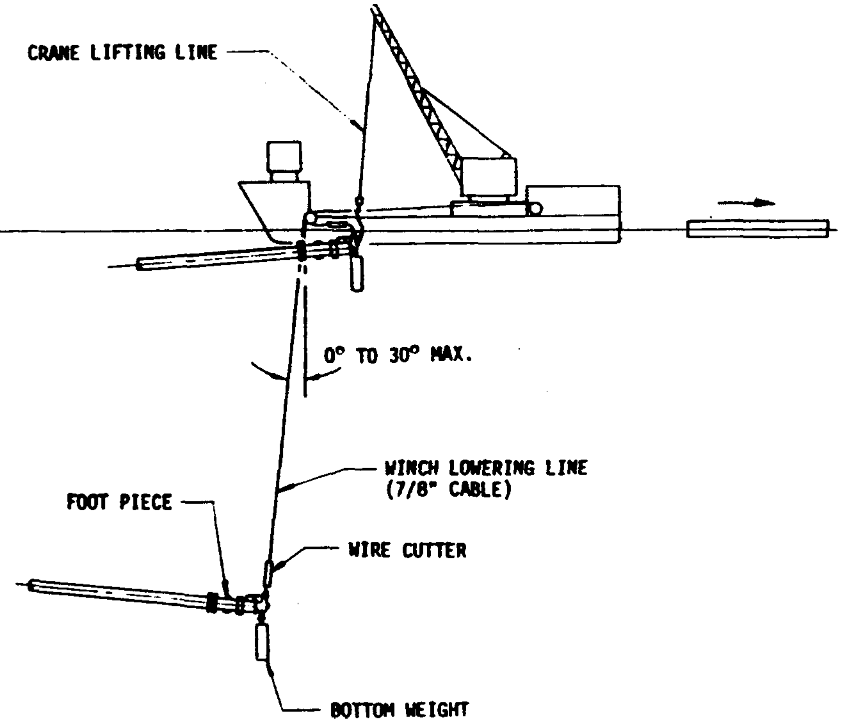
2. BOAT 'C' MAKES READY TO PULL TRANSPORT BARGE CLEAR OF THE LIFTED BOTTOM END ASSEMBLY.

3. ALL SAFETY LASHING ON THE FOOT PIECE ARE REMOVED. ALL PERSONNEL CLEAR THE LIFTING AREA.

> NOTE: CARE MUST BE TAKEN DURING LIFTING TO KEEP SCLAIRPIPE CLEAR OF PEDESTAL STAND. LIFT ONLY AS HIGH AS NECESSARY TO MINIMIZE BENDING OF SCLAIRPIPE.

4. LIFTING COMMENCES. THE WEIGHT SHOULD NOT SLIDE ALONG THE BARGE DECK. DECK.





XII A. PIPE UPENDING - PHASE I

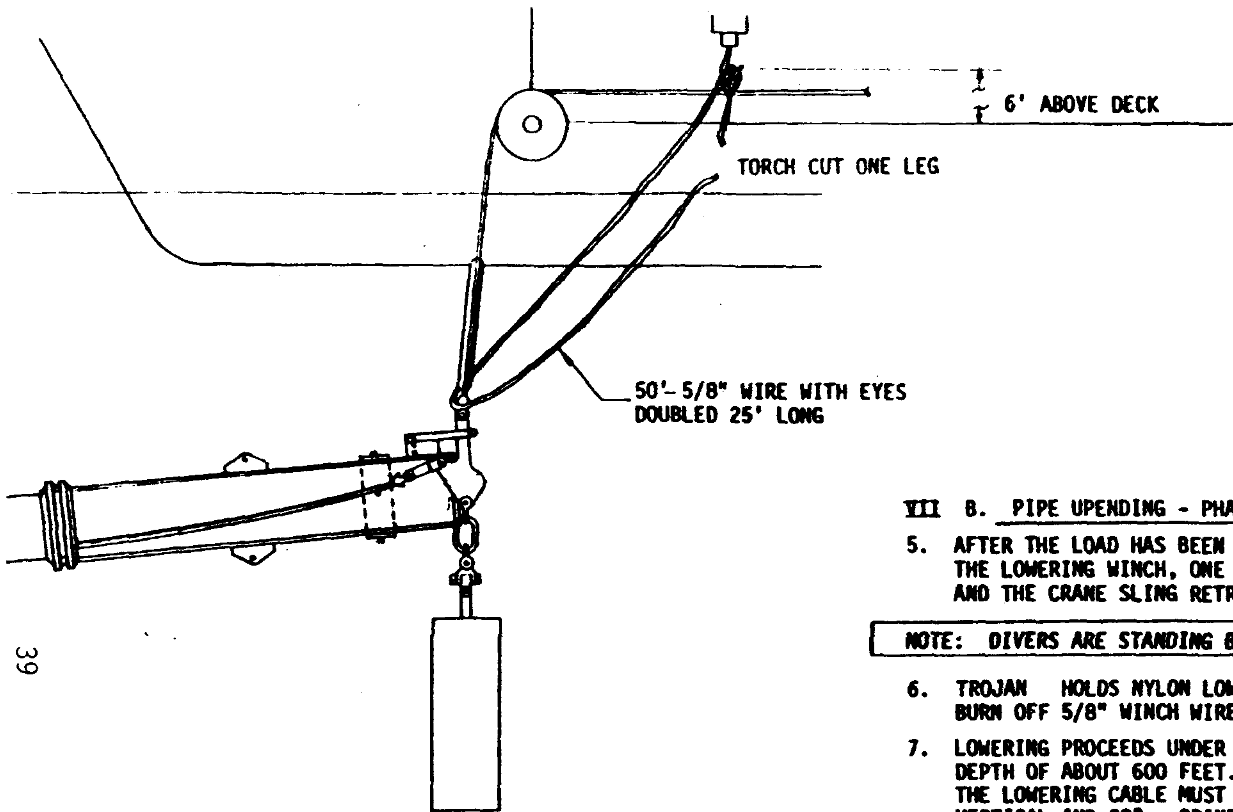
1. CRANE BARGE SAMSON USING CRANE BOOM LIFTS BOTTOM END ASSEMBLY FROM TRANSPORT BARGE. AFTER ASSEMBLY IS CLEAR OF TRANSPORT BARGE, THE BARGE IS PULLED CLEAR BY BOAT 'C'.
2. USE AIR TUGGER FRAPPING LINE TO KEEP ASSEMBLY UNDER CONTROL IN THE TRANSVERSE DIRECTION.

> NOTE: WHEN PIPE IS RAISED, DO NOT LOWER BOTTOM END UNTIL ALL AIR HAS EXHAUSTED COMPLETELY.

3. AS LOWERING BEGINS ALL AIR WILL BE BURPED FROM PIPE.
4. THE CRANE LOWERS ASSEMBLY APPROXIMATELY 10 FEET BELOW THE SURFACE AS THE LOAD IS TRANSFERRED TO THE LOWERING LINE AND WINCH.

> NOTE: CHECK POINT - GMDI/GE APPROVAL TO FURTHER LOWERING MUST BE OBTAINED.

> NOTE: DYNALINE TENSIONER WITH RECORDING CAPABILITY AND FOOTAGE COUNTER WILL BE USED TO MONITOR LOWERING LINE LOAD AND LINE PAYED OUT.



VII B. PIPE UPENDING - PHASE I (CONTINUED)

5. AFTER THE LOAD HAS BEEN TRANSFERRED FROM THE CRANE SLINGS TO THE LOWERING WINCH, ONE END OF THE CRANE SLING IS BURNED OFF AND THE CRANE SLING RETRIEVED.

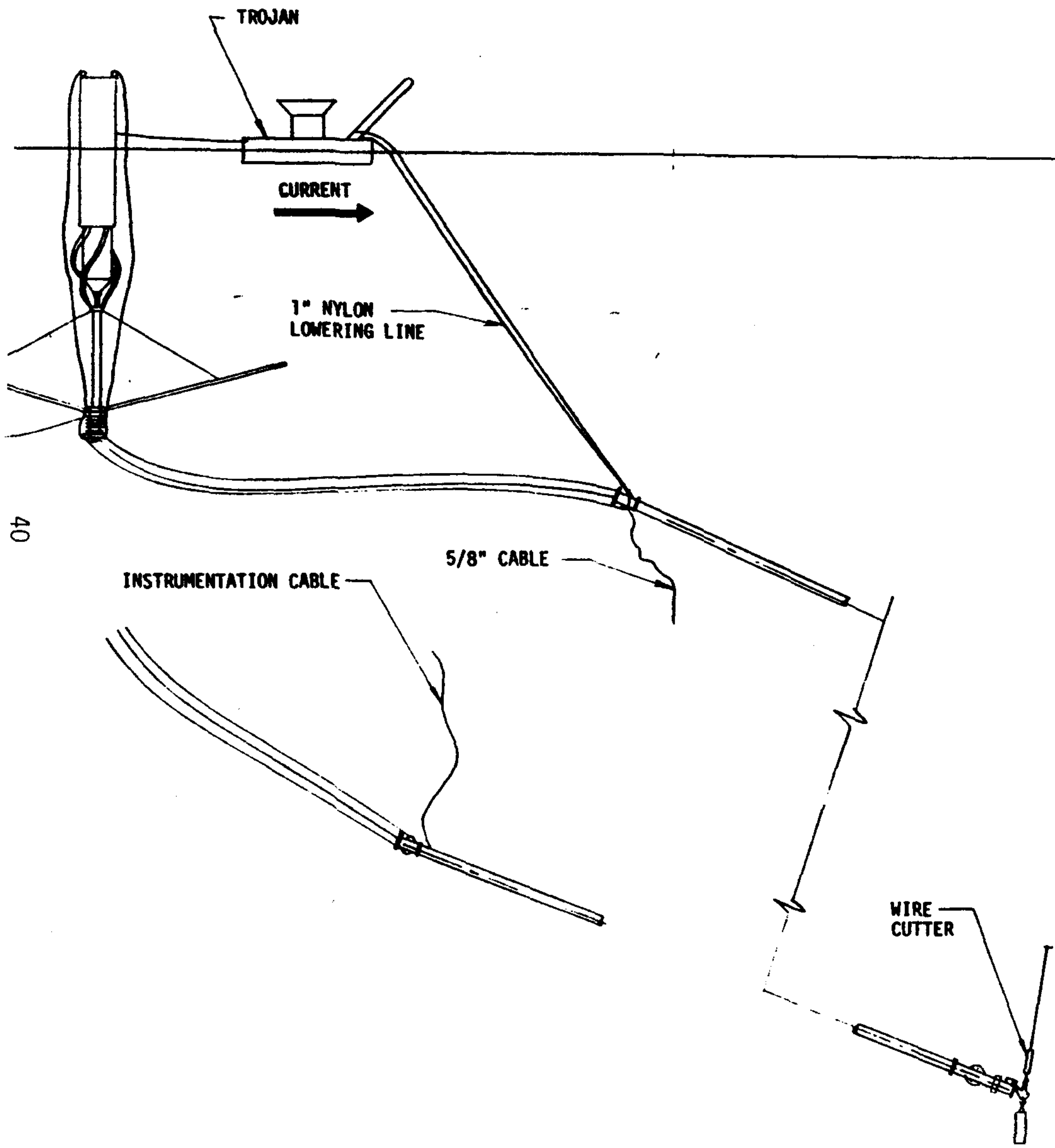
NOTE: *DIVERS ARE STANDING BY TO CLEAR SLING IF IT FOULS.*

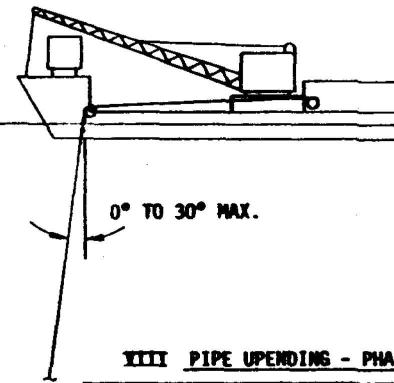
6. TROJAN HOLDS NYLON LOWERING LINE AND LETS 5/8" WINCH WIRE GO SLACK. BURN OFF 5/8" WINCH WIRE AND LET FALL.

7. LOWERING PROCEEDS UNDER POWERED CONTROL OF THE LOWERING WINCH TO A DEPTH OF ABOUT 600 FEET. LOWERING IS DONE UNDER POWER - NOT ON BRAKE. THE LOWERING CABLE MUST ALWAYS TEND TOWARD MACHINERY BUOY BETWEEN VERTICAL AND 30°. CRANE BARGE SAMSON SHOULD MANEUVER ONLY VERY SLOWLY TO MAINTAIN MACHINERY BUOY HEADING AND TO KEEP CLEAR OF MOORING SYSTEM. MANEUVER CRANE BARGE SAMSON AS REQUIRED TO MAINTAIN CABLE ANGLE SPECIFIED.

NOTE: WINCH COMMUNICATOR CALL OUT LOWERING LINE FOOTAGE EVERY 100 FEET.

NOTE: MONITOR CRANE BARGE SAMSON WINCH LOWERING LINE LOAD. DO NOT LET LOAD DROP BELOW 5000 POUNDS MINIMUM OR EXCEED 30,000 POUNDS MAXIMUM.





XIII PIPE UPENDING - PHASE II

NOTE: TENSION IN TOP END LOWERING LINE SHOULD BE VISUALLY OBSERVED ONCE BOTTOM END LOWERING IS STARTED. IF TENSION BECOMES MARKEDLY GREATER, SLACK OFF. MAKE SURE INSTRUMENTATION CABLE IS FREE TO RUN IN THE EVENT THE LOWERING LINE MUST BE SLACKED SUDDENLY.

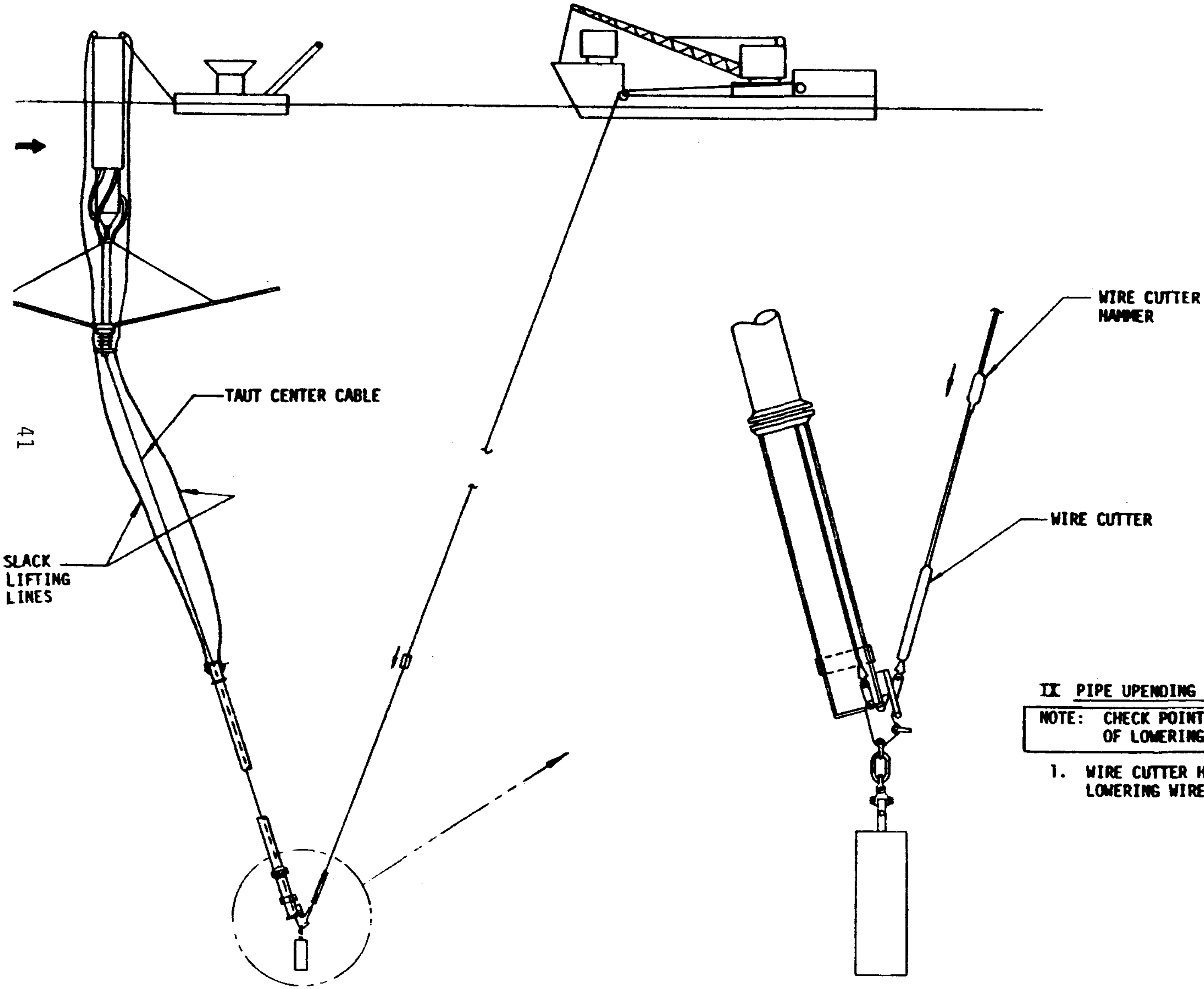
1. WHEN THE BOTTOM END COMMUNICATOR CALLS OUT 600 FEET (FROM THE WINCH FOOTAGE COUNTER)TROJAN CUTS DEAD END OF LOWERING LINE. SLACK OUT INSTRUMENTATION CABLE AS REQUIRED. RETRIEVE LOWERING LINE.

NOTE: DO NOT USE TROJAN PROPELLERS AT ANYTIME WHEN INSTRU-
CAUTION MENTATION CABLE IS OVER THE SIDE.

2. CRANE BARGE SAMSON CONTINUES TO LOWER BOTTOM WEIGHT AN FOOT PIECE UNTIL FOOTAGE COUNTER IS AT 1200 FT. STOP LOWERING OPERATION.

NOTE: MONITOR CRANE BARGE SAMSON WINCH LOWERING LINE LOAD DO NOT LET LOAD DROP BELOW 5000 POUNDS MINIMUM OR EXCEED 30,000 POUNDS.

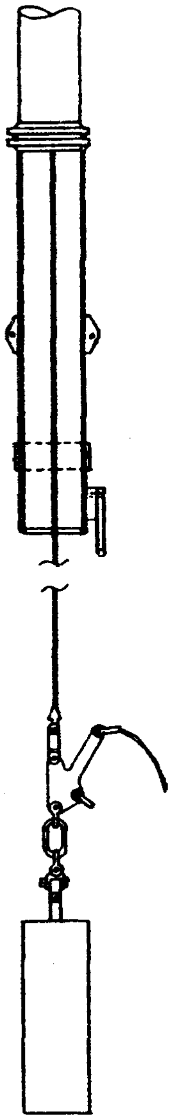
3. CRANE BARGE SAMSON SHOULD MANEUVER TO KEEP LOWERING LI BARGE ANGLE WITHIN 0° TO 30° RANGE.



IX PIPE UPENDING - PHASE III

NOTE:	CHECK POINT - GMDI/GE APPROVAL TO PROCEED WITH RELEASE OF LOWERING LINE MUST BE OBTAINED BEFORE GOING TO STEP

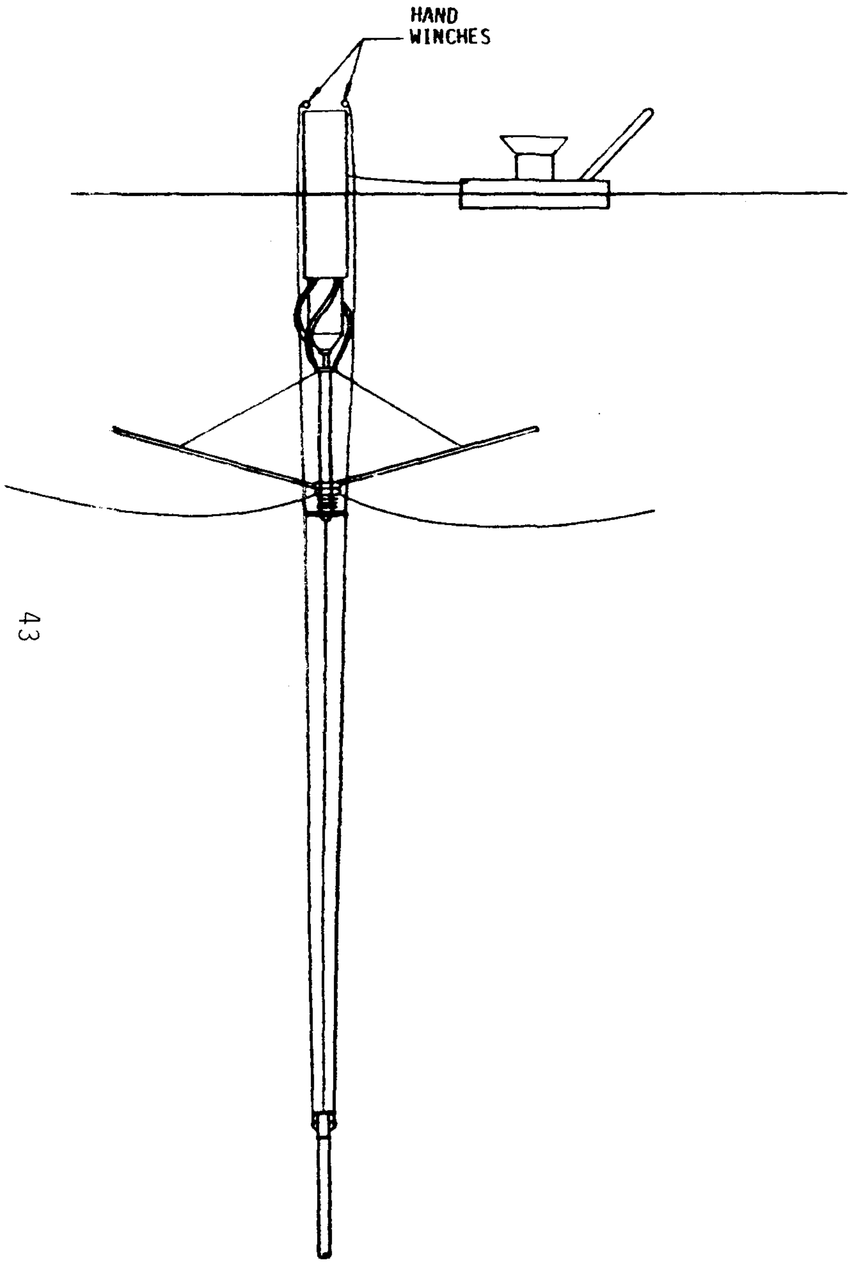
1. WIRE CUTTER HAMMER IS RUN DOWN THE LOWERING LINE TO CUT LOWERING WIRE AND RELEASE BOTTOM WEIGHT.



X PIPE SWING

1. AS THE PIPE SWINGS TO VERTICAL POSITION, THE LONG TONGUE WITH CUT WIRE ROPE WILL SLIDE CLEAR OF THE FOOT PIECE BAIL.

2. CRANE BARGE SAMSON RETRIEVES LOWERING LINE AND CUTTER.

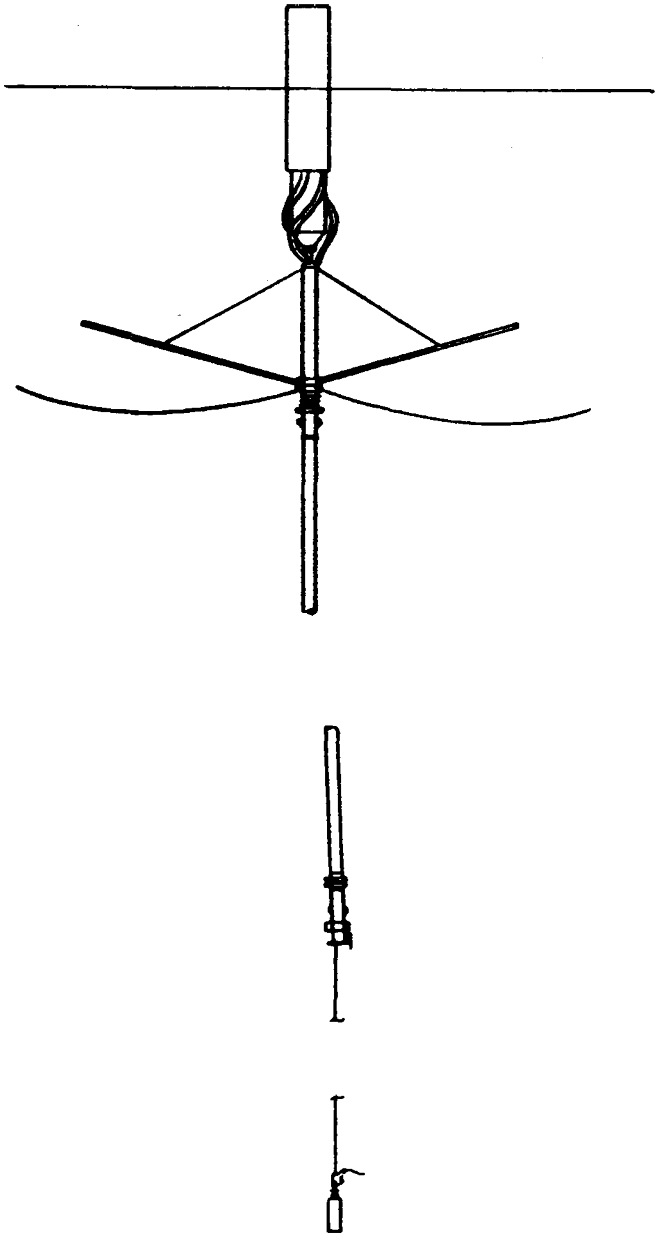


XI RAISING PIPE TO MATE WITH BUOY

1. DIVERS SHOULD MAKE A VISUAL INSPECTION OF THE LOWER UNIVERSAL JOINT & HARDWARE AS WELL AS THE LIFTING LINES AS FAR DOWN AS PRACTICAL.

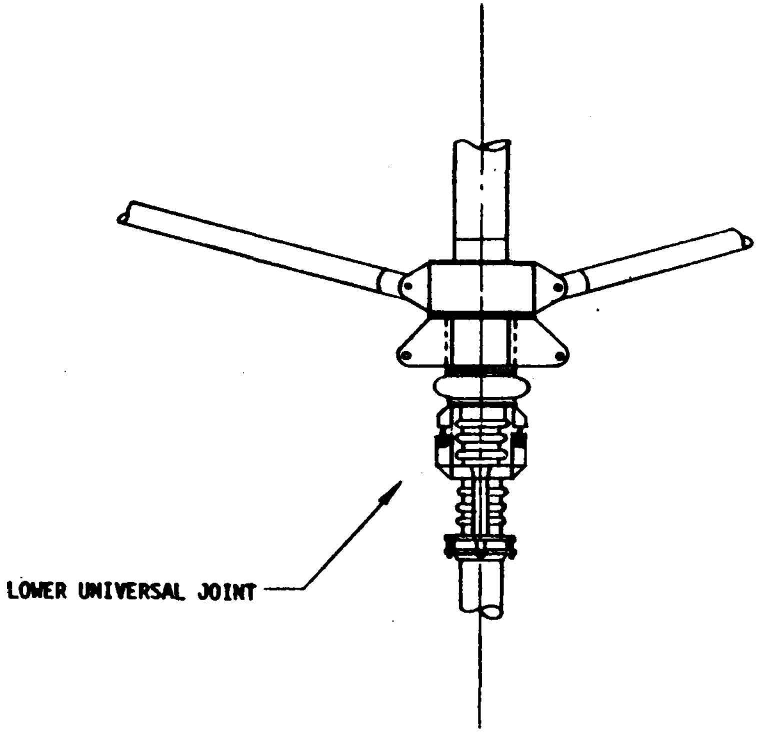
NOTE: CAUTION	BOAT 'B' SHOULD TAKE UP THE SLACK IN THE INSTRUMENTATION CABLE AS THE PIPE IS RAISED.

2. PIPE IS RAISED WITH LIFTING LINES USING HAND WINCHES ON BUOY UNTIL THE TOP OF THE PIPE IS ABOUT 10 FEET BELOW THE LOWER UNIVERSAL JOINT.
3. DIVERS REMOVE FOUR TURNBUCKLES FROM LOWER UNIVERSAL JOINT AND SEND TO SURFACE. UNIVERSAL IS NOW FREE TO ROTATE IN BOTH DIRECTIONS.
4. REMOVE RESTRAINING CLIPS ON HORN ASSEMBLY.
5. DIVERS OBSERVE MATING OF TOP END OF PIPE FLANGE WITH BUOY AND DIRECT WINCH OPERATORS.
6. FLANGE BOLTS ARE INSTALLED AND TIGHTENED BY DIVERS. BOLTS ARE TIGHTENED USING DIVER ASSIST TOOLS. SECURE BOLT LOCKING WASHERS.



III. PREPARE BUOY FOR OPERATION

1. REMOVE LIFT LINES, TRANSFER INSTRUMENTATION CABLE TO BUOY, REMOVE LIFTING WINCHES, ETC.
2. DIVERS PERFORM GENERAL INSPECTION OF SYSTEM.



SECTION I - ATTACHMENT B

MEASUREMENT OF POLYETHYLENE PIPE PARAMETERS
DURING TEST FARM PIPE
DEPLOYMENT

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SUMMARY

This program was conducted to acquire data on the behavior of the polyethylene upwelling pipe for the GRI/DOE Marine Biomass Biological Test Farm during several phases of pipe assembly and ocean towing and deployment. The pipe is nominally 28 in O.D., 1,400 feet long with wall thicknesses of 0.9 and 1.75 inches. The entire effort was conducted over a period of six weeks and was implemented on a strictly non-interference basis with the main Biomass Program.

Three types of data were acquired during shore and ocean based operations conducted in the southern California area during the period from 15 September - 27 September 1978. Axial strain data were obtained from two rows of 15 transducers each, separated circumferentially by 90° and distributed along the entire length of the pipe. Photographic data were also acquired from helicopter, boat and shore stationed cameras. Both 16 mm motion pictures and 35 mm slides were taken. Strain-transducer and photographic data were acquired during beach assembly operations and during a tow and up-ending operation which subsequently had to be aborted before any significant pipe lowering was accomplished.

The third type of data acquired were lowering line tension measurements made during the second successful deployment operation. No strain data were acquired since the sensor harness system was irreparably damaged during the earlier deployment attempt.

The sensor system performed well until problems with the deployment were encountered. Although data reduction/analyses were outside the scope of this program, a limited data scan was conducted. The maximum strain level recorded was only 0.5% and that was encountered in going over the sea wall during assembly

operations. Maximum strains measured at sea during tow were on the order of 0.1%. The most severe bend introduced in the pipe was also seen in going over the sea wall. Minimum bend radii during the towing operations are estimated to be no less than 350-400 feet which is approximately 175 to 200 pipe diameters compared to the sharpest allowable bend of 50 pipe diameters. The lowering line average tension during the final lowering operation was approximately 18,000 lbs compared to the allowable range of 5,000 - 30,000 lbs defined in the deployment plan. Large, transient tension variations (min. 10,000 to max. of 30,000 lbs) were observed during passage of large swells or in a few cases, when the lowering cable shifted on the payout drum. No difficulties were encountered due to these variations.

Several recommendations are made for consideration in future data acquisition efforts of this type.

1.0 INTRODUCTION AND BACKGROUND

The Energy from Marine Biomass Program originated by GRI and presently jointly sponsored by GRI and DOE deployed the first Biological Test Farm off Laguna Beach, California in September 1978. The objective of the testing is to demonstrate and quantitatively evaluate the controlled growth of the California Giant Brown Kelp (Macrocystis pyrifera) in an open ocean environment using deep nutrient-rich water to fertilize the plants. The upwelled water is pumped to the surface from a depth of 1,400 feet through a large 28 in O.D. polyethylene (PE) pipe with nominal wall thicknesses of 1.75 inches (upper 600 feet) and 0.92 inches (lower 800 feet). The pipe (DuPont of Canada, Sclairpipe) was planned for assembly on the beach at Dana Point, California with a nine-mile open ocean horizontal tow to the site of the installation (33° 30' N, 117° 51' W). The pipe was then to be upended to the vertical position and attached to the previously installed buoy system containing pumps, etc.

Early in 1978, NOAA and GE began discussing the possibility of obtaining "piggy-back" data on the behavior of large PE pipes during ocean operations from the Marine Biomass upwelling pipe installation. The data are of interest to NOAA (and DOE) for application to design of OTEC cold water pipe (CWP) systems presently in progress and planned for the future. Since some of the CWP concepts involve the use of PE pipe, although significantly larger than the biomass upwelling pipe, the biomass pipe installation provided a near term and relatively inexpensive opportunity to acquire the "piggy-back" data on a non-interference basis. A limited program was finally initiated near the end of July 1978 to acquire strain sensor data, photographic data, and line load information during the biomass pipe assembly and installation. The program was welcomed and approved by the main Biomass Program Sponsors with the understanding that the pipe instrumentation and data tasks were to be on a strictly no-interference basis with main program operations and/or schedules. Although previous GE experience in ocean data systems permitted a rapid engineering definition of the instrumentation system, only six weeks were available to design the system, procure materials, fabricate/assemble and calibrate the instruments, and ship to the California field site. This was a marginal schedule period for such a program involving hardware acquisition and necessarily limited the scope of design trade-offs and material purchase options due to the extremely short delivery requirements. In view of the non-interference nature of the program, this was accepted as a hard, unalterable schedule constraint.

2.0 PROGRAM CHRONOLOGY

Contract effort was initiated 21 July 1978. Three separate tasks were conducted: (1) Plan, design, and build strain sensor instruments and acquire strain data; (2) Plan and implement photographic data acquisition; and (3) Plan and implement measurement of tow/lowering line tensions. A major field operation occurred 18 September 1978 when strain and photographic data were acquired during a pipe deployment operation which subsequently had to be aborted due to changing weather conditions. Field operations ended 27 September 1978 with acquisition of lowering line tension data during the second and successful pipe installation. A limited in-house data scan was completed in Philadelphia 26 October 1978. A history of program events is presented in the following chronology. A more detailed chronology for events associated with strain instrumentation and data acquisition is presented in Section 3.1.4.

OVERALL PROGRAM CHRONOLOGY

July 21	-	Contract effort initiated.
July 27	-	Helicopter, Photographer, GMDI P.O.'s initiated.
Aug. 2	-	Coordination meeting with GMDI, Newport Beach, California: Instrument compatibility, cable routing, on-board recording, mooring plan, work boat availability.
Aug. 3	-	Briefing of NOAA personnel at GMDI, Newport Beach, California.
Aug. 4	-	Strain harness design completed.
Aug. 7	-	Major harness parts ordering completed.
Aug. 11	-	Dyna-Line tensiometer P.O. initiated.
Aug. 18	-	Major harness parts delivered to Philadelphia.
Aug. 23	-	All shipboard recorders/instruments assembled, calibrated at Philadelphia. Final boat power requirements defined.
Aug. 24	-	Monthly Progress Report presented to NOAA/OOE.
Aug. 28	-	Strain harness fab/cal complete in Philadelphia. All shipboard recorders/instruments received in California.
Aug. 30	-	Strain harness equipment received in California. Review buoy/substrate cable routing/buoy penetration design, and inspect hardware at Bethlehem Shipyard, L.A.
Sept. 5	-	Dyna-Line tensiometer received in California.
Sept. 7	-	Photography coordination/planning meeting at GMDI.
Sept. 8	-	Work boat "Trojan" available for loading instruments.
Sept. 9	-	Instruments loaded on "Trojan", checkout initiated.
Sept. 12	-	Shipboard generator installed on "Trojan", calibration completed at shipyard, Newport Beach, California.
Sept. 14	-	"Trojan" with instrumentation aboard arrives Dana Point Harbor pipe assembly site. First pipe sections fused. Prepare for installation of first strain sensors.
Sept. 15	-	Begin installation of sensor units and cables on pipe. Approximately half of units installed by end of day.

Sept. 16 - Remaining pipe sections assembled, all but last three sensors installed on pipe.

Sept. 17 - Remaining sensors installed, pipe completed and launched over sea wall into harbor. (See detailed Chronology Section 3.1.4)

Sept. 18 - Final install/checkout on "Trojan" completed (0345)
Helicopter first arrives on site (approx. 0645)
Begin tow to site (0856)
Arrive at farm (1200)
Start pipe deployment operation (1230)
Flood pipe to start sinking operation (1545)
Pipe washed under buoy, harness failures (1604)
Helicopter coverage terminated (approx. 1630)
Abort deployment operation (1730)
Begin return tow with flooded pipe (1800)
Arrive/secure Dana Point Harbor (2100)
(See detailed Chronology Section 3.1.4)

Sept. 19 - Completed preliminary inspection of harnesses

Sept. 20 - Completed pipe damage inspection, made decision to repair before another deployment attempt.

Sept. 21 - Completed final inspection of cable damage. Determined repair not feasible. Identified alternates. Off loaded recording system from "Trojan".

Sept. 22 - Plans for pipe repair completed/approved.

Sept. 23 - Prepared to refloat pipe.

Sept. 24 - Blew water out of pipe, refloated in harbor.

Sept. 25 - Towed pipe out of harbor to turn around, reverse ends. Pulled damaged end up on beach. Decision made not to reinstrument pipe and to remove harnesses and sensors.

Sept. 26 - Pipe repaired, relaunched prepared for tow. Remaining sensors/cables removed.

Sept. 27 - Begin operation/preparations (0000)
Initiate tow (0200)
Arrive farm site, take current readings (0530)
Align pipe in proper sector, initiate operations (0630)
Initiate footpiece lowering/tension measurement (1015)
Complete lowering operation (1115)
Cut lowering line to complete upending (1130)
Initiate raising for mating with buoy (1200)

Sept. 29	-	Complete hookup to buoy and final mating. Installation complete at 1300 hours.
Oct. 10	-	Set up and calibrate data scan instruments at Philadelphia.
Oct. 11	-	Begin limited data scan-magnetic tapes/movie film
Oct. 26	-	Complete data scan

3.0 DISCUSSION AND RESULTS

Three independent tasks were accomplished.

- Strain sensor harnesses were designed, fabricated, and installed on the pipe. Data were acquired during the tow and installation operations of 18 September 1978.

- Photographic data were recorded during the pipe assembly and sensor installation operations on the beach at Dana Point, California. Photographic records were also obtained from surface vessels and a helicopter during the installation operations of 18 September 1978.

- Lowering line tensions were measured and recorded during the successful pipe installation of 27 September 1978.

The following subsections describe the instrument systems, measurement techniques and results for the three tasks. Conclusions and recommendations are presented in Sections 4.0 and 5.0 respectively.

3.1 Strain Sensor Data

The basic design was developed during the first week of the program and remained essentially unchanged. The hardware was fabricated, installed and utilized to acquire ocean data on 18 September 1978. On that date, it sustained severe damage during an aborted operation, and after review of several options, was removed from the pipe prior to final installation. The following sub-sections describe the harness design, fabrication, and installation, the 18 September 1978 data acquisition, and a discussion of the results of a limited data scan of the recorded data. A discussion of the damage sustained in the aborted mooring and the rationale for the no-repair decision are also discussed.

3.1.1 Strain Sensor Harness Design/Fabrication

Two harnesses were fabricated with 15 strain transducers on each harness. The system was designed to mount on the outside surface of the upwelling pipe and to measure axial strains in the polyethylene pipe material. The two harnesses were installed on two axial lines along the entire length of the pipe with the two longitudinal rows of sensors displaced by 90 degrees around the pipe circumference. The sensors were distributed uniformly along the length of the pipe except that some were positioned to measure strain across butt-fused joints, at section midpoints, and above/below a wall-thickness transition section. (See Table 1)

3.1.1.1 Harness Cables

The harnesses were fabricated from Spectrastrip 25 Conductor/24 gage ribbon cable with 10 mil PVC insulation. Wire samples were subjected to an underwater pressure test where the test sample was cycled between ambient and 750-1000 psi two times to assure the basic integrity of the insulation, at least for a short time period. After approximately 2 1/2 hours under pressure and two days in an ambient pressure sea water test, no measurable degradation in insulation resistance was noted. In addition, the specimen was high-potted to 2 KV in salt water at 1000 psi with no evidence of insulation breakdown. A more extensive quantitative evaluation and testing of cable insulation were precluded by the extremely tight scheduling. This particular cable was selected because of previous experience at GE with the bonding and potting of urethane to this cable for underwater applications, and the short-term (2 week) delivery available from Spectrastrip in the lengths required. Plans were made to overcoat the cable insulation with 3M Scotch Kote (a liquid PVC compound) to reduce water absorption. Although several different techniques were tried, it was not feasible to apply a coating of acceptable quality within the available time either in the fabrication shop or in the field.

The harnessing was designed such that each cable supplied the needs of fifteen four-wire sensors. In the upper harness section of about 450 feet, fifteen of the 25 conductors were designated as signal leads, 5 as +28 volt D.C. power and 5 as common power and signal ground. At a location near the top of the pipe, the cable was cut. Then, starting at the bottom end of a long (~1400 ft.) piece which would be near the bottom end of the pipe, the cable was cut and stripped in such a way that three wires (power, signal, ground) terminated at each desired sensor location. This provided a harness for eight sensors, all with independent leads. The 22 conductor end of the stripped off "scrap", i.e., that end which had been near the bottom, was then reversed and aligned with the 25 conductor (upper) end of the eight sensor harness. This piece of cable was cut and stripped to provide another independent harness for the remaining seven sensors. The upper 450 ft. piece of 25 conductor cable and the two harnesses were wired together in such a way that each power and ground lead in the upper cable supplied three sensors, i.e., 3 signals, 1 common power, 1 common ground, while all sensor leads were still independent in the lower harnesses. The joint area was potted into a urethane block which could be mechanically fixed to the pipe. This arrangement is shown schematically in Figure 1. In this way, maximum use was made of the available cable, and the number of solder joints was reduced to a minimum.

The cables were fabricated such that 10% slack would result when the sensors were installed at the stations listed in Table 1.

The fabrication of the "B" cable was modified slightly because one length of cable was broken during manufacture and was delivered in two pieces. One piece was 800 feet long and the other was 1200 feet long. The harness fabrication was handled as above except the junction block was located at 1200 feet instead of

1460 feet, and some of the added wires ran upward in the second harness instead of all running downward.

3.1.1.2 Sensor Attachment

The sensors selected for the measurement were DC to DC LVDT's with a ± 0.500 inch stroke, manufactured by Trans-Tek, Inc.

A full description can be found in Attachment 1. The four sensor leads were cut short, stripped, and soldered to the applicable harness leads. The sensor power ground lead and signal ground lead were commoned at this point. The sensors were then clamped to the harness by the mounting clamp as shown in Figure 2. The solder joints and harness wires were then potted to the sensor body (see Figure 2). The opposite end of the sensor body was also potted to preclude the possibility of sea water seeping between the sensor shell and coil spool. As the sensors were attached to each harness, they were identified 1 thru 15 with sensors 15 at the intended top of the array and 1 at the bottom.

3.1.1.3 Calibration

The sensors were individually calibrated by mounting each sensor vertically above an adjustable horizontal platform upon which a 0.500" thick block rested. A core was inserted and was supported by the block and platform. With 28 ± 0.001 VDC applied to the end of the harness, the platform was adjusted until the sensor output was nearly zero. The "zero" output was recorded. Then the block was removed and the output was again recorded. These data are listed in Table 2. The derived position and strain sensitivities are also listed.

After calibration, each core was placed in a bag labeled with the identification of the sensor it was calibrated with. The core cavity of each sensor was then injection filled with silicone grease. The grease would keep sea water out of the core cavity and prevent the accumulation of foreign material which might interfere with core movements. A laboratory test unit was fabricated in this configuration and placed in a salt water bath to obtain information on the effectiveness and potential life of the water-proofing technique. After approximately six weeks (last check) no change in performance had been observed in the test unit output.

During calibration, it was discovered that the three units in a group were inactive. This is apparently caused by the input voltage change at the transducer because of current changes in the common 28 V line as the current changed with each unit's output change. The interaction was significant (several per cent) if one of the units was driven through its maximum current change by completely removing the core from the unit.

If the core movement was limited to the operating range of the unit, the interaction was insignificant (less than 1%). To eliminate the effect during calibration, each sensor sharing the common power leads with the unit under test was adjusted to an output of less than 1% of full scale.

3.1.2 Harness Installation

Figure 2 illustrates the installation details of the LVDT sensor unit. To accomplish the installation, a drill jig was used to provide alignment and location of the four mounting screws. The LVDT body was mounted first. Then the core was screwed into its mounting bracket and the assembly was slid into position and fastened to the pipe. Both LVDT body and core mounting brackets were attached with self tapping screws in blind holes.

Excess grease extruded from the core cavity by the core insertion was wiped away, but leaving a generous fillet of grease between the core shaft and sensor body. Power was then applied to the sensor, and all three sensors in the group were adjusted to zero ± 0.1 volts output. The sensor which had just been mounted was then fine adjusted to zero ± .03 volts and locked. All the screws in the assembly were then "locked" with RTV silicone rubber. In order to provide some protection from flow and other operational hazards, the installation was then covered with a 9", diameter polyethylene fairing held to the pipe with four self-tapping screws.

The pipe was cleaned at five foot intervals with naptha, and the cable was taped to the pipe with two wraps of glass tape covered with four wraps of yellow, vinyl tape. The 10% slack was evenly distributed between the tape wraps. The yellow tape was used along with yellow fairings to enhance photographic visibility and provide reference marks.

Because of variations in pipe section lengths and the desire to bridge pipe joints with some of the sensors, it was not always possible to mount the sensors at the planned stations. The actual sensor locations are listed in Table 1.

The sensors were installed in two rows, located at ± 45° from the top center line of the pipe as it came out of the welding machine. Consistent azimuthal alignment of the sensor rows along the pipe length could not be maintained, however, since the pipe sometimes had a tendency to roll or twist after it passed into the water over the sea wall. Final azimuthal locations can be measured from the photographic data obtained before and during the tow. "A" was -45° looking toward footpiece.

The pipe passed over a set of rollers at the edge of a wall as it went down into the water from the beach assembly area. At low tide, the pipe was about seven feet above the water at the wall and contacted the water at a point about 50 feet from the base of the wall. In passing over the rollers, the pipe assumed a noticeably oval cross section. The output of LVDT B3 was monitored as its section of pipe passed over the rollers and entered the water. The measured strain was + 0.237% (stretch) crossing the rollers and - 0.540%

(compression) entering the water. These measurements were made at low tide. These are the largest strain values seen in any of the data scanned to date.

3.1.3 Shipboard Data System and Data Record Format

A block diagram of the data recording system installed aboard the "Trojan" is shown in Figure 3. Recorders 1, 2, and 3 were 14 channel tape recorders. Recorder 3, as used, had only seven channel capability in the main frame. The other seven channels were available through an additional chassis which was not used in this operation. Voice annotation was recorded on Recorder 1 edge track, and time code was recorded on one data channel of each recorder. IRIG B time code was used. This provided a thirty-two data channel tape recording system. The three chart recorders provided eight additional channels of hard copy data for real-time viewing and evaluation.

The tape recording system was calibrated to record ± 10 volt inputs. Each channel of tape recorders 1 and 2 was adjusted to a 54 KHz center frequency, a ± 40% deviation for ± 10 volts in and for an output of ± 2.5 volts for ± 10 volts in. Each channel of recorder three was adjusted as above except the center frequency was 27 KHz. The calibration of the chart recorders was checked, and did not need adjusting.

On the morning of the tow, -5 volts was sequentially applied to each tape recorder channel (except the time channels) for calibration. Annotation of when the signal was applied to each channel was recorded on the Recorder 1 voice edge track.

Tape recorder channel allocations are listed in Table 3. Chart recorder channel allocations are annotated on the charts.

Tape recorder speeds were set at 15 I.P.S.

3.1.4 Detailed Strain Data Chronology & Events

Assembly of the pipe and instrumentation installation began on Friday, September 15, 1978 and was completed Sunday, September 17, 1978. Sunday afternoon, the pipe was inadvertently moved with an anchor rope still attached. The rope slid and rolled along the pipe for a considerable distance. The sensor harness insulation on both arrays was severely damaged, and the leads were torn out of one sensor in the "A" array near the top end of the pipe.* Repair of this damage which extended over about 30 ft. of cable, required several hours of effort ending at approximately 0030 the morning of the tow. As a result, the mating of the sensor arrays to the data recording system, consequently, was not completed until 0330 hours, September 18, 1978. Spot checks of the recorder channels indicated that the systems had not drifted significantly since they were adjusted several days before; therefore, it was decided that an entire system realignment was not required.

* Although not specifically discussed, several other instances of cable damage during the assembly/fabrication processes occurred. These were generally caused by normal handling procedures for the pipe and were repaired with field repair techniques used in previous underwater hardware programs. The damage on 17 September 1978, however, was by far the most extensive and difficult to repair.

On September 18, 1978, the following events occurred at the indicated times.

0844 We began the recorder calibrations. To accomplish this, one of the power supplies was disconnected from the "B" sensor array, was adjusted to 5.00 VDC and was connected to a B.N.C. cable as a -5.00 V.D.C. cal signal. Then, starting with Recorder 1, channel 1, the sensor signal cable was disconnected, the cal. cable was connected, the voice track was annotated with recorder and channel number, the cal. cable was disconnected and the sensor signal cable was reconnected. This sequence was repeated, for each recorder channel except those with time code. During the cal. period, the "B" array sensors which would normally have been powered by the power supply being used for calibration were of course not working.

0856 The "Sampson" and "Trojan" began to move the pipe toward the harbor exit.

0858 The calibration power supply was re-installed in the system and power was restored to the effected "B" array sensors. At that time, it was noted that the AC power switch was off on one of the other power supplies. Whether the switch was bumped off during re-installation of the "calibration" supply or was off all morning is unknown. In any event, by 9:15, all supplies were on.

0918 The "Sampson" exited the harbor mouth.

0929 It was noted that Recorder 2 was not operating properly. All squelch lights on the playback boards were blinking. The condition deteriorated rapidly until the lights were constantly lit. The "Trojan" exited the harbor.

0949 Completed a series of tests on Recorder 2 which indicated the record boards were operating properly. Sensor outputs were checked and were nominal. Output boards were not providing meaningful information.

1024 Began to switch sensors from Recorder 2 to spare channels on Recorders 1 and 3 and to activate the standby strip chart recorder. Recorder 2 had failed completely. The tape drive had overheated and failed. We believe the problem was in the tape drive/sync system. If there is any data on tape 2-1, it is probably not at the right frequency (due to improper tape speed) and will be difficult to recover.

1200 The "Trojan" came abreast the mooring site and began applying reverse power.

1206 "Trojan" began backing into the farm sector at full reverse power.

1221 "Trojan" stopped max power backing and began to maneuver into position.

1228 "Trojan" was moored, engines shut down.

1300 The remaining two recorders finished their second reels and the data recording system was shut down. Difficulties were being encountered with lowering preparations and the noise from the 115 volt generator was interfering with communications.

1542 The generator was restarted and the data recording system was turned back on. Sensor/recorder channel relationships had been switched around in an attempt to obtain data from as many sensors as possible. The open top end of the pipe had been lowered to sea level. The pipe was rubbing against the side of a mooring spring buoy.

1546 Time code generator was reset. On turn-on at 1542, it actually set itself to 2050. The exact relationship was 1546:00 = 2054:06.

1546:20 The open top end of the pipe was lowered to approximately ten feet below sea level and began to sink along its length. The pipe immediately went under the mooring buoy due to a shift in current.

1548-1552 The pipe apparently came in contact with the anchor line attachment hardware under the mooring buoy and destroyed the "B" array harness. The "A" array harness was being battered against the bottom of the buoy.

1600 A search for sensors still providing useful information was largely negative. Current measurements on the four power supplies indicated that the harnesses were so badly damaged that it would be impossible to separate valid signals from fluctuating shorts, opens and interactions.

1612 The decision to abort the mission had been made. The recording system was shut down. The generator was stopped. In order to prevent any possible interference by the sensor harnesses with the dangerous job of disengaging the pipe from the buoy, the harnesses were cut where they came aboard the Trojan and cleared from the area.

On September 19, 1978, the sensors and harnesses were inspected. In the buoy area, the harnesses were severed and some of the sensors were completely or partially missing. Outside the impact area, the sensors seemed in good condition. The harnesses, however, had suffered significant damage along almost the entire length. In some areas, the slack had been pulled from several taped sections and was concentrated in a single long loop. In one case, the pulling force had broken the lead wires just outside the potting on the end of the sensor. The exact source of the pulling forces is unknown except that significant pull and stretch could be anticipated if the harnesses snagged on hardware parts during the encounters with the spring buoy. Some cable damage may also have been due to the sustained punishment to which the entire system was subjected, particularly after pipe flooding. The pipe lay awash with waves breaking over and around the cables for a period of 5-6 hours during the installation attempt and on the return tow. Damage was most severe in areas where the harness slid under the tape. In some cases, conductors were broken inside the insulation. In other cases, both conductors and insulation were broken and/or damaged. In any event, the multiple failures observed along the cables caused the harnesses to be suspect at every tape ring and effectively eliminated any hope of salvaging useful lengths of wire or repairing the cables.

3.1.5 Data Record Description

(a) Tape 1-1

Tape recorder 1 functioned well during tape #1 (0830 to 1030). A loose part in the tape guiding mechanism caused the lateral position of the recorded tracks (especially the voice edge track) to be slightly variable. The voice modulation is low and may require additional amplification. There is a damaged (stretched) section of tape just after the calibrations caused by a rewind accident. The duration of the calibration inputs were necessarily very brief resulting in some difficulty in calibrating a readout device.

The data illustrated in Figure 4 were taken from tape 1-1 for the time period the pipe was rounding the sea wall. The strains due to bending the pipe while exiting the harbor and the increased wave motion effects as we cleared the harbor are evident.

Figure 5 illustrates data from the end of tape 1-1 (1030 to 1033). The sensors are all working well.

(b) Tape 1-2 (1053 to 1300)

During this interval, some sensor malfunctions in the "A" harness began to appear. Figure 6 illustrates pipe tension, bending and wave motion as the "Trojan" backed into the farm area and moored to the machinery buoy. Noise spikes such as on the A13 and A12 traces are probably interactive power fluctuations caused by an intermittent in power supplying their stable-mate A5. A list of sensor common power groups is presented in Table 4 and should be very useful in identifying possible interactions. We have concluded that recorder problems are effecting A8, A9 and possibly A6 at this time. By the end of tape 1-2, sensor channels A1, A6, A8, and A9 had probably failed. The other sensors were either working or were recorded on tapes we could not review. No failure analysis has been conducted to define the potential causes of apparent sensor failures.

(c) Tape 1-3 (1542 to 1612)

The time code reading at the beginning of this tape is 2050 but is erroneous. At 1546, the time code generator was reset to the correct time. The relationship is 1546 = 2054:06. Figure 7 illustrates a data sample at the beginning of the tape from some of the sensors on Recorder 1.

(d) Tape 2-1

A playback of this tape showed time code and cal signals were properly recorded, at least at the beginning. We could not find any data. If data is present, its retrieval will require more sophisticated play back equipment than we used for our quick look.

(e) Tape 3-1, 3-2, 3-3

The carrier frequency on this tape is 27 KHz at 15 I.P.S. Our play back equipment was set for 54 KHz and could not provide us with a quick review of these tapes.

(f) Recorder 6 (Millimeter Chart)

This recorder was originally set to record strains on the order of 10% (10V). By 9:53, it was obvious that strains were very low. Therefore, the range was set to a more reasonable value, (.05 volts/cm). At 10:00, the speed was increased to clearly show the wave action. At 10:26, this recorder became the primary and only recorder for sensors A1 and A3 due to Recorder 2 failure. Just after the arbitrary 75 minute mark, sensor A1 signal began to show spikes. At 11:38, that unit had apparently failed and the recorder was switched to B8 which was not being recorded on any recorder. Between 13:00 and 15:42, the recorder was switched to B1 and B2. At 15:49:30, both

B1 and B2 shifted scale (B2 off scale). At 15:51:30, the outputs indicated harness destruction.

(g) Recorder 5 (Inch Chart)

This recorder was activated after Recorder 2 failed and was the primary and only record for B11 and B12 from 11:20 until 13:00. Chart speed was 2"/minute, sensitivity was 0.1 volts/inch. At approximately 12:38, a large swell hit the "Trojan" and progressed along the pipe. We annotated the chart with the words, "Big Wave". The progression of this swell can be followed on the other records. Between 13:00 and 15:42, the recorder was switched to B14 and 15. At 15:49:30, B14 and B15 indicated harness destruction.

(h) Recorder 10 (4 Channel H.P.)

Although this recorder was turned on early on the morning of the tow, it was not again monitored and readjusted until just before 10:00. By 10:10, a sensitivity of 0.05 volts per small division and a speed of 10 mm/min had been selected. Sensors A2, B1, A15, and B15 were being recorded. At 10:30, Recorder 10 became the primary and only recorder for B15, B13, B14 and A2. Just before 11:30, A2 showed anomalous outputs and the recorder channel was switched to B10. Actually, A2 was reacting to the failure of A1. Later, A2 provided good data. At 12:16, the recorder speed was increased to 25 mm/min to better resolve the wave action. We could not increase the sensitivity of the recorder without inducing a servo buzz which resulted in pen/paper writing difficulties. Between 13:00 and 15:42, the recorder was switched to B10, B11, B13, and B12. At 15:49:45, the sensor harnesses were destroyed by buoy impact.

3.1.6 Harness Damage and Termination Decision

As noted above, both harnesses were broken at the point of impact with the spring buoy and very severely damaged for some distance along the cable length in this area. In addition, however, the close post-abort inspection showed that extensive and much more subtle damage had occurred, primarily at the tape rings, over almost the entire pipe length. In some cases, this damage was only detectable by close visual inspection of the cables and consisted of wire breaks inside insulation which was apparently undamaged. Additionally, a complete inspection was impossible since 1,000 ft. of the pipe length remained in the water resulting in certain section of cable being accessible for inspection (or later repair). Under these conditions, the entire length of cable was suspect and was deemed unacceptable for further use.

The first option considered was to obtain new cables, checkout sensors, and reinstall at least one row of sensors. This was not feasible since:

- New cable delivery times were totally incompatible with program schedule.
- The number of field joints and splices required would probably have resulted in unacceptably low hardware reliability.

- Installation of a complete harness was impractical since two thirds of the work would have to be accomplished on the length of pipe section still in the water.

The schedule impact was, by far, the overriding consideration.

A second, less ambitious option was considered. Two 450 ft. lengths of cable (those sections which were originally used to bring the data from the top end of the pipe into the shipboard data system) were available and were probably undamaged. The alternate plan evaluated was to salvage checkout and reinstall several sensors along the top 450 ft. of the pipe using one length of cable as a harness and the second length again to bring data aboard the ship. This approach was also rejected for the following reasons.

- Data during tow and initial farm-situ operations were already available. Primary need for further data was to make strain measurements <u>near the bottom of the pipe</u> during the footpiece lowering. This option could not place sensors below 450 ft. station.
- Again, the entire installation would be made up of extensive field joints and some limited need for working on the pipe in the water was indicated. Poor hardware reliability was again considered a potential problem.
- Minimum estimated turn around time to accomplish this option was estimated at "several days to a week", even assuming 12-hour work days and no significant problems. Compatibility of this delay with the main program schedule was, at best, marginal.

The negative decision was based on a combination of the schedule delay, potential reliability problems and the questionable value of the new data acquired since lower-end measurements were not feasible.

No other viable options could be identified. The accessible sensors were then salvaged as feasible. The cables were removed to avoid potential interference with installation operations.

3.2 Photographic Data

Photographic data were recorded on both 16 mm movie film and 35 mm still slides. Both types of equipment were employed from shore, boat, and helicopter platforms during assembly operations, and during the tow and initial installation attempt of 18 September 1978. No photography was done during the installation operation of 27 September 1978. All of the assembly operations (related to pipe repair), towing and surface-visible installation operations were essentially the same as those photographed on the previous attempt. A total of two hours of 16 mm, silent movie film (four, 30 minute reels, 24 frames per second) were taken. Overhead helicopter coverage of the tow and operations at the farm site comprise almost one entire reel. The other three reels contain coverage shot from various vantage points around the Dana Point assembly site and aboard two vessels on station during the operations. Approximately 160, 35 mm slides were taken from the same locations as the movies, and, in fact, were generally taken at various intervals between movie sequences.

As would be expected, the resolution of the 35 mm slides is superior to that of the resolution in the 16 mm movies. In the case of the slides, even when the camera was far enough away to frame all or almost all of the 1,500 ft. assembled pipe, the yellow, circular flow shields over the sensor stations are usually distinguishable and in many cases, the yellow tape bands spaced at 5 ft. intervals are resolved. With distant (or high altitude) movie views, it was not possible to resolve the flow shields or the tapes, but the pipe curvature could be related to the pipe length of 1,400 ft. to obtain an absolute reference for a quantitative estimate of bending radii. Several views in both movies and slides would permit a quantitative evaluation of the bending radii encountered in going over the sea wall into the water during assembly at Dana Point. The highest strains and sharpest bend radii were encountered during this operation. A time-correlated listing of events documented on the four movie reels is presented in Tables A-4 and A-5 of Appendix A.

3.2.1 Helicopter Operation

The helicopter employed was a Hughes 300, piston-engined machine with only room for the photographer and pilot. The original plan to use a larger turbine-powered, multi-place Hughes 500D had to be changed to accommodate the changing pipe deployment schedule. None of the larger machines were available for the final date of the operation. The smaller machine also made the technical photographic task more difficult since it did not have a cabin-floor port for straight-down shots and had significantly higher noise and vibration levels. Its flight endurance was 1 hour and 45 minutes.

The helicopter initially arrived over the Dana Point area at first light on the morning of the operation. Some initial photographs were taken of the pipe secured in the harbor prior to start of towing operations. The helicopter returned to photograph the tow out of the harbor and was on station taking pictures until the "Trojan" at the trailing end of the tow cleared the breakwater. Adverse lighting conditions (angles and intensity) forced utilization of high speed movie film with somewhat reduced resolution and also limited available viewing angles since it was difficult to see the dark pipe against the dark ocean background even with the yellow markers. During this phase of the operation, the helicopter's altitude was kept relatively high in order to keep the entire pipe in the frame. The bending induced by tow vessels in exiting the harbor is clearly visible and radii are estimated to be 25-30% of the 1,400 ft. pipe length. No kinking or anomalous bending behavior was observed at any time; all observed bends were relatively smooth and uniform.

The helicopter returned several times during the steady tow to the farm site and took pictures from various altitudes and aspect angles. As the day progressed, the lighting conditions improved resulting in better photographic quality. Even at the lower altitudes from the airborne pictures, it is difficult to gain an appreciation for the flexibility of the pipe in riding over the waves and swells during the tow. This quality of the pipe is, however, quite clearly seen in some of the surface camera views.

The helicopter maintained station almost continuously (within its endurance limitations) during the entire afternoon's operations at the farm site. Both 16 mm movie and 35 mm still coverage of all aspects of the installation attempt were obtained including the initial positioning of the pipe, its slow drift toward the spring buoy, its flooding and eventual submergence under the buoy which led to the decision to abort. The helicopter terminated operations late in the afternoon after the abort decision.

In general, the overall behavior of the pipe is clearly seen in the helicopter movie shots but only estimates of curvatures relative to pipe length are possible when the frame shows the entire pipe. In the case of the 35 mm slides, the measurement resolution is somewhat improved since the tapes and flow shield are sometimes resolvable. In many cases, however, the camera angles would cause accurate quantitative analysis to be difficult due to required geometrical corrections.

3.2.2 Surface Camera Operations

Surface camera primary function was to document beach and ocean operations in 16 mm movies and 35 mm slides. Cameras on shore and boats did provide adequate coverage of all aspects of these operations both at the Dana Point site and at the farm site.

Limited film was also acquired which could be analyzed to obtain quantitative estimates of pipe motion during the tow. The lateral oscillations of the pipe, caused primarily by waves and swells arriving at angles off the tow direction, can be resolved from some of the boat photography during the tow. Similarly, the vertical oscillations over the waves are clearly visible in some shots with sufficient resolution to make distance measurements. The analysis would be complicated again, however, by camera angles and in this case also by camera boat motion. It is easily seen that the pipe motion follows that of the ocean surface which on the day of the operation varied between three and six ft. swells with periods on the order of six sec.

It should be noted that serious consideration was given to the feasibility of underwater photography during the operations at the farm site. One of the photographers was equipped with underwater cameras and is a qualified diver. It was decided, however, that in view of the complexity of the operation, the size of the hardware, and the number of lines in the water at any given time, underwater photography presented an unacceptable risk to personnel. This was further justified by the fact that water clarity was relatively poor during the operation so that opportunities for safe and meaningful underwater photography would have been almost nil that day.

3.3 Line Load Data

The original intent of this task was to measure tension loads in tow and tag lines during the tow to the mooring site and to measure tensions in the lowering line attached to the footpiece/pendulum weight during the pipe upending operation. The objective was to provide quantitative data on external loads applied to the pipe which could then be correlated with strains measured/predicted from strain sensor and photographic data.

The final mooring plan as described in Ref. 1 called for mounting of the pipe footpiece (leading end of tow) on a transport barge which also carried the nine ton pendulum weight. The top end of the pipe with the horn assembly (trailing end of the tow) was rigged up out of the water and carried by a line over the "A-frame" boom on the bow of the "Trojan". Because of the complexity of this final rigging configuration and the "hard" connections to the vessels, no reliable way existed to obtain meaningful towing load data.

As shown in Ref. 1, the pipe upending operation also involved a number of load and control lines between which loads were transferred during various stages of the operation. In particular, at the upper, horn end of the pipe, the loads were transferred between a number of synthetic lines and wires ropes during the upending and mating operations. Again, the complexity of the rigging system and the load transfer plan made effective measurement of meaningful line load data infeasible. The rigging configuration at the lower, footpiece end of the pipe, however, involved only a single primary lowering line after the pick of the footpiece and pendulum weight off the transport barge. The initial lift was performed by the crane on the D/B "Sampson" but the load was quickly transferred to the "Sampson's" lowering winch system at a depth of 10 ft. During the remainder of the lowering operation, the weight of both the pipe assembly (PE and steel footpiece) and the pendulum weight was carried by the single winch lowering line from the "Sampson". The lines were arranged such that necessary reaction to any horizontal component of the lowering line tension off the "Sampson" was supplied either by the nylon lowering line off the "Trojan" or, subsequently, by the pipe center cable pulling against the

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Ref. 1 - Pipe Mooring Plan/Procedures by GMDI moored machinery buoy (see diagrams in Reference 1, Sheets VIII, IX - Pipe Upending - Phases II, III).

A three-sheave tensiometer was installed on the "Sampson" winch lowering line approximately 5 ft. in front of the winch payout system. This type of device was selected instead of a load cell to permit tension measurements on a running line. The unit was a Martin-Decker Dyna-Line Wireline Tensiometer Model No. UD-12-RU rigged for the 7/8" IWRC wire used for the lowering line. The rented unit was supplied with a gage readout which was not compatible with timely conversion to chart or tape recording so tension data were read and recorded manually during the lowering operation. The range of the unit was 0-40,000 lbs. with an easily-readable resolution of 200-300 lbs. The readout gage was provided with a damping adjustment which was adjusted such that transient load variations of duration significantly less than a second could be detected.

The line on the payout drum was marked off at 50 ft. intervals with flags to indicate the length of line out as a function of time. During the lowering operation, an observer positioned at the tensiometer readout station recorded time, tension, and line length out. Another observer was stationed at the fairleader where the lowering line turned down into the water approximately 50 ft. forward of the winch station. The second observer recorded time, cable footage and estimated (visual) lowering line angle. The arrangement of winch, fairleader, etc., on the "Sampson" is shown in Reference 1.

No tensiometer data were taken on the first installation attempt of 18 September 1978 since the operation was aborted prior to initiating bottom-end lowering operations. A complete set of tension readouts was recorded on the successful operation of 27 September 1978. The results are presented in the chart of Figure 8 which shows tension, line angle, and time from start of lowering as functions of length of line deployed. It is seen that the average values of tension held at around 17,000-18,000 lbs. during most of the one-hour lowering operation. Variations were generally on the order of ± 2,000 lbs. with a few larger variations of up to ± 10,000 lbs. observed with passage of unusually large swells or with "jumping" or slipping of individual cable turns on the payout drum. Fluctuation periods of two seconds were "typical". The transient tension excursions observed had no detectable effect on the overall smoothness of the lowering operation. The final "holding" tension at the end of the payout, prior to cutting the lowering line to complete the upending operation, was 11,000 ± 500 lbs. Line angles (0° referenced to vertical) during the operation varied from 0° at the initial lowering, to a maximum value of 25°. The line angle rapidly reached 15° - 20° shortly after the start of the operation. There appears to be no clear correlation between tension and line angle but it could easily be masked by the transients in the tension data.

4.0 CONCLUSIONS

The scope of the present effort was limited to design of data system and acquisition of strain data, photographic data, and loads data during the assembly and deployment of the upwelling pipe for the Marine Biomass Test Farm. The following conclusions are based on experiences with the planning, design, implementation, and operation of the data systems and also on results of a limited sampling of some of the data after the field operations.

4.1 Strain Measurements

1. The overall strain data system performed well.
2. Significant data on PE pipe strains were acquired during assembly and ocean operations.
3. The largest strain value reduced from the data was 0.54% going over the sea wall. Data sampled from tow and ocean operations are significantly below that level.
4. The DC - DC LVDT is ideally suited as a strain sensor in this application and exceeded the required dynamic range.
5. The 10% strain capability of the system was not required. Both LVDT sensitivity and cable slack requirements could be safely modified for max strains of 2% or 3% with significant margin still remaining.
6. Major data system failure was caused by severe pipe impact(s) with spring buoy at the farm site.
7. This system, cables in particular, was vulnerable to rigors of marine operations and associated rough handling.
8. This system, in spite of vulnerability, was easily repaired in the field for limited damage.
9. An armored cable system would probably have suffered similar but more limited damage, but would not have been as easily field reparable.

4.2 Photographic Data

- Movie and slide film were acquired to provide adequate documentation of all above-water operations.

- Estimates of pipe curvature radii are possible from the films.

- Minimum bending radii observed during tow and ocean operations were about 175-200 pipe diameters. A more severe bend occurred in going over the sea wall during assembly but no quantitative estimate was made from the films.

- The tape system employed to enhance photographic visibility was marginal for 16 mm helicopter photography techniques employed. Sufficient resolution is probably obtained with 35 mm film but further analysis is required.

- Early morning lighting conditions were poor for overhead photography of the black pipe against the sea background.

- The small Hughes 300 helicopter had significant drawbacks as a technical photographic platform in this application.

4.3 Line Load Data

- The Dyna-Line tensiometer provided a useful tool for the required tension measurements.
- Adequate line-load and line-angle data were acquired.
- Line loads and angles were easily maintained within ranges specified in the mooring plan.
- Large transients in tension were observed due to sea motion and cable adjustments on the winch drum. These had no measurable effect on the lowering operations.
- No clear correlation between line tension and lowering angle was found.

5.0 RECOMMENDATIONS

The following recommendations are made based on the results and conclusions noted above:

5.1 Strain Measurements

- No further analysis of present data is recommended except possible correlation of measured strains with pipe bend geometry estimated from photos and/or estimating wave shapes.
- Install systems of this type in future PE pipe deployment operations to monitor strain levels.

- Future systems for PE pipe applications should be designed for much less than the 10% strain capability built into this system.

- Future systems should be designed for installation <u>inside</u> the pipe if at all possible. An alternative approach might be to develop a "hardened", externally-installed system to increase probability of survival under the extreme handling conditions, but this is not an easy task since adequate "hardening" could easily alter the basic strain properties of the pipe.

- Several more detailed hardware related recommendations are:
    - Continue the use of mechanically - fastened DC - DC LVDT's as strain sensors in these applications.
    - Eliminate common power or ground leads to sensors, if possible, to avoid interactions if channels fail.
    - Minimize slack in cabling to be consistent with requirements of reduced strain levels.

- Provide significantly increased lead time for procurement and installation of systems of this type.

5.2 Photographic Data

- Perform limited additional data analyses to obtain estimates of pipe curvature over sea wall and verify existing estimates from helicopter shots.

- Employ helicopter photography in future pipe deployment operations.

- In future operations, provide for longer term commitment of larger turbine-powered helicopter. Aircraft should be capable of carrying photographer and technical observer, provide for straight-down photographic shots and carry RF compatible with vessel communication.

- Recommendations for improving detailed technical quality of photographic data are:
    - Increase emphasis on 35 mm stills versus 16 mm movies to improve resolution for quantitative analyses. If pipe motion data is of primary interest, rely on sequences of rapid stop-action 35 mm stills rather than "continuous" 16 mm movies.
    - Take advantage of improved helicopter capability noted above for straight-down shots where possible.
    - Provide for pre-operation test flight to "calibrate" photographic conditions from helicopter. Critical lighting aspect-angle, and target visibility should be evaluated prior to definition of final photographic plan.

5.3 Line Load Data

- No further analysis of available data is recommended.
- Continue use of 3-sheave tensiometer device for line load measurements of this type in future operations.
- Provide for automated strip-chart recording of output readings.

TABLE 1

STRAIN SENSOR LOCATIONS

NOTE: Stations in feet from top end of first pipe section.

SENSOR I.D. NO.	PLANNED LOCATION ROW A	PLANNED LOCATION ROW B	ACTUAL INSTALLED LOCATION ROW A	ACTUAL INSTALLED LOCATION ROW B
15	50 FT.	50 FT.	50 FT.	50 FT.
14	150	100	150	100
13	250	200	250	200
12	390	300	390	300
11	420	330	420	330
10	550	490	550	490
9	630	600	630	600
8	740	700	742.75	700
7	850	800	855	800
6	950	900	955	900
5	1,050	1,020	1,055	1,020
4	1,080	1,110	1,080	1,109.6
3	1,150	1,200	1,150	1,200
2	1,250	1,300	1,250	1,300
1	1,370	1,370	1,370	1,370

TABLE 2

SENSOR CALIBRATION

(+ strain (stretch) produces decreasing output.)

SENSOR	"0" OUT	0.5" OUT	VOLTS/INCH	% STRAIN/VOLT
A15	+ .007	- 14.968	- 29.95	- 0.835
B15	000	- 14.119	- 28.238	- 0.885
A14	+ .003	- 14.862	- 29.73	- 0.841
B14	000	- 13.826	- 27.652	- 0.904
A13	- .002	- 14.467	- 28.93	- 0.864
B13	+ .004	- 14.167	- 28.342	- 0.882
A12	+ .008	- 14.512	- 29.04	- 0.861
B12	+ .006	- 14.328	- 28.668	- 0.872
A11	- .009	- 14.463	- 28.91	- 0.865
B11	+ .006	- 13.687	- 27.386	- 0.913
A10	- .007	- 14.313	- 28.61	- 0.874
B10	- .006	- 13.762	- 27.512	- 0.909
A9	+ .001	- 14.277	- 28.556	- 0.875
B9	- .003	- 13.748	- 27.4[illegible]0	- 0.909
A8	+ .001	- 13.900	- 27.802	- 0.899
B8	+ .001	- 13.552	- 27.106	- 0.922
A7	+ .007	- 14.123	- 28.26	- 0.885
B7	- .006	- 13.357	- 26.702	- 0.936
A6	+ .002	- 13.635	- 27.274	- 0.917
B6	- .003	- 13.414	- 26.822	- 0.932
A5	- .005	- 13.780	- 27.55	- 0.907
B5	+ .006	- 13.700	- 27.412	- 0.912
A4	000	- 13.698	- 27.396	- 0.913
B4	+ .006	- 13.011	- 26.034	- 0.960
A3	- .006	- 13.696	- 27.38	- 0.913
B3	+ .005	- 13.200	- 26.41	- 0.947
A2	- .007	- 13.390	- 26.766	- 0.934
B2	000	- 13.317	- 26.634	- 0.939
A1	- .002	- 13.592	- 27.18	- 0.920
B1	000	- 13.045	- 26.090	- 0.958

TABLE 3

TAPE RECORDER CHANNEL ALLOCATIONS

RECORDER	CHANNEL	0830 TO 1300 HRS. SENSOR (OR FUNCTION)	1542 TO 1600 HRS. SENSOR (OR FUNCTION)
1	Edge A	Voice	Voice
1	Edge B	Blank	Blank
1	1	A5	A5
1	2	A6	A6
1	3	A7	A7
1	4	A8	A8
1	5	A9	A9
1	6	A10	A10
1	7	A11	A11
1	8	A12	A12
1	9	A13	A13
1	10	A14	A14
1	11	A15	A15
1	12	B9	B9
1	13	A4 (after 10:24)	A4
1	14	Time Code	Time
2	Edge A&B	Blank	-
2	1	A4	-
2	2	A3	-
2	3	A2	-
2	4	A1	-
2	5	B15	-
2	6	B14	-
2	7	B13	-
2	8	B12	-
2	9	B11	-
2	10	B10	-
2	11	B8	-
2	12	B7	-
2	13	B6	-
2	14	Time Code	-
3	1	B1	B7
3	2	B2	B8
3	3	B3	B3
3	4	B4	B4
3	5	B5	B5
3	6	Blank	B6
3	7	Time Code	Time Code

TABLE 4

SENSOR COMMON POWER GROUPS

GROUP #	SENSORS IN GROUP
1	A1, A2, A15
2	A3, A4, A14
3	A5, A12, A13
4	A6, A7, A11
5	A8, A9, A10
6	B1, B2, B15
7	B3, B4, B14
8	B5, B12, B13
9	B6, B7, B11
10	B8, B9, B10

TABLE A-1

Distance from Tape Start (Approx.)	Time (Local)	Magnetic Tape 1-1 Voice Track Chronology for 9/18/78 Event
40 Ft.	0323:	- Pre tow cals in progress (night)
80	0844:52	- Start, AM cals before initiating tow (these continue for several minutes)
950	0856:	- Tow started
	0858:	- All sensors recording
1350	0901:	- Mixup on channels being recorded
2120 2350	0912: 0915:	- Power supply #3 not turned on, Check channels effected
2580	0918:	- Lead end of pipe clears jetty
3354	0929:	- Trojan clears end of jetty. Also note problems with Recorder #2.
4900	0949:17	- Do not know whether Recorder #2 is recording data or not. Problems with mainframe and tape drive. Will not fix.
	1016:12	- Tow/sea state information: Tow speed ~3 kts, wave height ~6 ft., period ~6 sec.
7500	1024:21	- Switched channels around - put A4 sensor on channel 1-13.

TABLE A-2

Distance from Tape Start (Approx.)	Time (Local)	Magnetic Tape 1-2 Voice Track Chronology for 9/18/78 Event
25 Ft.	1053:45	- Time code data present, start recording (no voice)
5200	1202:50	- Pipe tow arrives at site, stopping motion
5352	1204:58	- Trojan begins backing hard to reverse tow. Not sure whether D/B Sampson has stopped all pulling on opposite end.
5490	1206:45	- Trojan starts backing into farm sector. Max. reverse, should be considerable tension in pipe now.
----	1218:35	- Trojan approaching mooring buoy, backing at max. power.
----	1221:47	- Trojan at mooring buoy, stops backing, begin maneuvering over to machinery buoy.
----	1228:39	- Trojan tied now to both mooring buoy and machinery buoy.
----	1233:38	- Waiting for wind/sea to straighten pipe in proper direction prior to beginning installation operations.
----	1238:18	- Big wave noted running down pipe.

End of Tape 1-2

TABLE A-3

Distance from Tape Start (Approx.)	Time (Local)	Magnetic Tape 1-3 Voice Track Chronology for 9/18/78 — Event
332 Ft.	1546:01	- Time code data present, start recording (no voice)
350	1546:20	- Note rearrangement of recorder channels to "afternoon" list due to failure of Recorder #2. Begin flooding horn-end of pipe. Pipe begins to sink.
1050	1555:55	- Pipe under mooring buoy, sensor array "B" apparently fails.
1700	1604:00	- Losing remaining sensors rapidly. Probably none of remaining sensors are giving reliable data.
2340	1612:47	- Terminate strain requirements, shut down all equipment.

TABLE A-4

LAMBERT FILM EVENTS (Beach & Helio)

Reel #	Time from Start	Event/Comment
1	0:00	Footpiece mating at Dana Point (9/15/78)
	4:15	Close up of strain sensor installation
	5:20	Lift footpiece over sea wall, install on transport barge.
	9:40	View of pipe with strain sensors, cables, tapes being fed over sea wall in preparation for next butt fusion.
	11:26	Method of pipe payout control using winch truck
	12:20	Preparation for next fusion at machine
	13:10	Aerial from helicopter, early morning views in Dana Point Harbor 9/18/78
	15:10	Start tow
	16:40	D/B Sampson at second jetty dogleg
	20:00	D/B Sampson abeam end of jetty on inside
	21:00	D/B Sampson begins turn to seaward
	21:40	Pipe mid point abreast end of jetty on inside
	22:50	D/B Sampson almost completes turn to NW.
	23:51	Pipe in "S" curve, probably max bending for this part of operation.
	24:46	Trojan passing end of jetty on inside, D/B Sampson has straightened pipe by turn to less northerly direction.
	26:39	Trojan abeam end of jetty heading seaward
	28:40	D/B Sampson turning to more northerly heading
	29:45	Steady, open-ocean tow established

Table A-4
Lambert Film Events (Beach & Helio)
Page (2)

Reel #	Time from Start	Event/Comment
1	30:40	Closer view of pipe under steady tow
	31:30	Continue pipe under steady tow
	34:30	End of Lambert Film (1)
2	0:00	Start with pipe in steady, straight tow
	1:30	Closer shot of pipe in steady tow showing strain sensors and tape markers
	3:42	Closeup of Trojan showing horn, rigging and instrument cables coming aboard.
	4:45	Start closeup run along pipe length
	5:37	Closeup of transport barge and footpiece end
	5:40	Approaching and passing test farm buoys
	9:15	Tow stopped, Trojan begins backing into farm sector for pipe installation operation
	10:40	Pipe bends entering farm sector clearly visible
	11:27	Probable max bend in pipe for this part of operation; Trojan approaches mooring buoy to put on a breast line
	12:50	Pipe bend decreasing, Walrus controlling barge
	14:10	Trojan moored to machinery buoy, pipe fairly straight at this point in time
	14:40	Pipe starts to drift noticeably toward buoy.
	16:25	Pipe about 80-100 feet from mooring buoy
	17:15	Closeup of Trojan, Horn, machinery buoy
	18:07	Pipe within 20 feet of mooring buoy
	20:15	Closeup run along pipe from foot-to-horn
	21:14	Pipe seen apparently against buoy
	22:09	Closeup of pipe against buoy

Table A-4
Lambert Film Events (Beach & Helio)
Page (3)

Reel #	Time from Start	Event/Comment
2	22:20	Initiate flooding of pipe from horn end
	23:10	Pipe apparently under mooring buoy
	23:30	Attempt to pull pipe away from buoy, large bend in pipe apparent
	24:30	Probably max bend in pipe for this part of operation
	25:10	View of entire pipe flooded and awash
	25:49	Sampson attaches to pull pipe off buoy
	26:49	Mathilda/Trojan pulling on pipe
	27:20	Closeup run along submerged pipe
	28:40	End-on view showing pipe bending around buoy
	29:15	End of Lambert Film (2)

TABLE A-5

GE FILM EVENTS (Beach & Boat)

Reel #	Time from Start	Comment/Event
1	0:00	Start with Dana Point pipe assembly, general shots
	1:15	Lifting footpiece over sea wall, start of pipe fabrication
	1:45	Fusing operation
	3:26	View from top of cliff showing pipe shape over sea wall
	5:10	Closeup of pipe, harness, tapes being rolled out over wall
	5:40	Transport barge and view of pipe from barge
	6:10	Closeup view of pipe in harbor from skiff run
	8:20	Joining operation procedures/other beach activity
	17:20	Closeups of sensors, installation of cables, etc.
	23:30	Upper-end stub flange and assembly of horn components
	28:00	Views of almost entire pipe in harbor (from island)
	30:00	Pulling center cable through, view from beach end
	31:00	Preparing to lift horn over sea wall, final assemble of horn and center-cable operations
	34:00	End of Reel #1
2	0:00	Horn being lifted over sea wall
	0:30	Repairing damage to sensor cables
	1:30	Horn-end on pontoon
	3:00	Horn on beach (second camera view)
	4:30	Horn being lifted over sea wall (second camera view)

Table A-5
GE Film Events (Beach & Boat)
Page (2)

Reel #	Time from Start	Comment/Event
2	5:45	Set up start of tow from Sampson
	7:30	At farm site
	8:25	Tow out of harbor (second camera)
	9:10	Views from farm site (second camera)
	11:15	Harbor views before tow (another camera)
	12:50	Begin tow out of harbor
	19:45	Views of helicopter from "Sampson"
	20:50	Arrive at farm site
	24:30	Views of pipe lying near farm buoys
	25:30	Preparation on transport barge
	27:15	Views of boat motion
	28:20	Towing flooded pipe back to Dana Point Harbor
	30:00	End of Reel #2

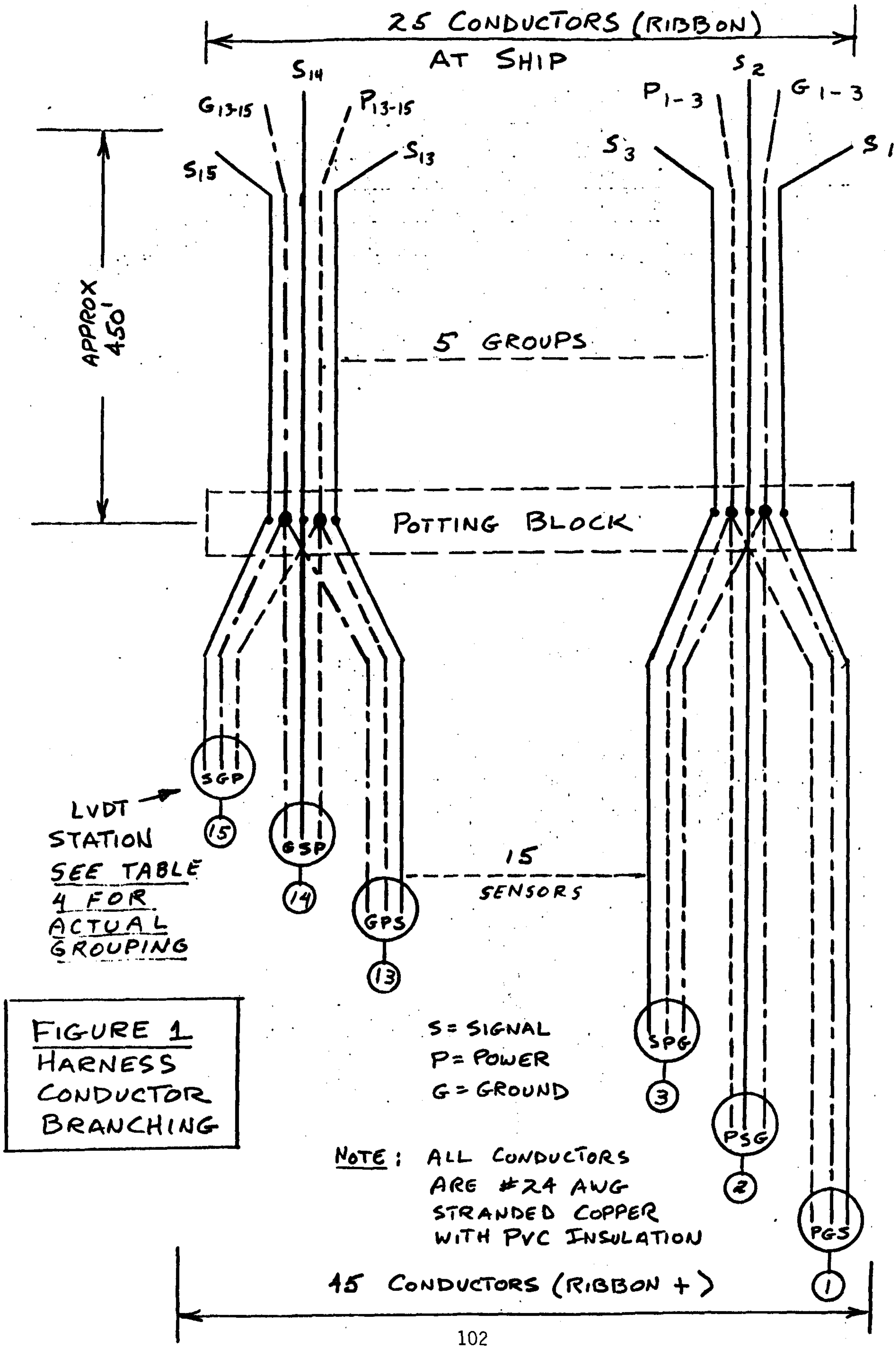
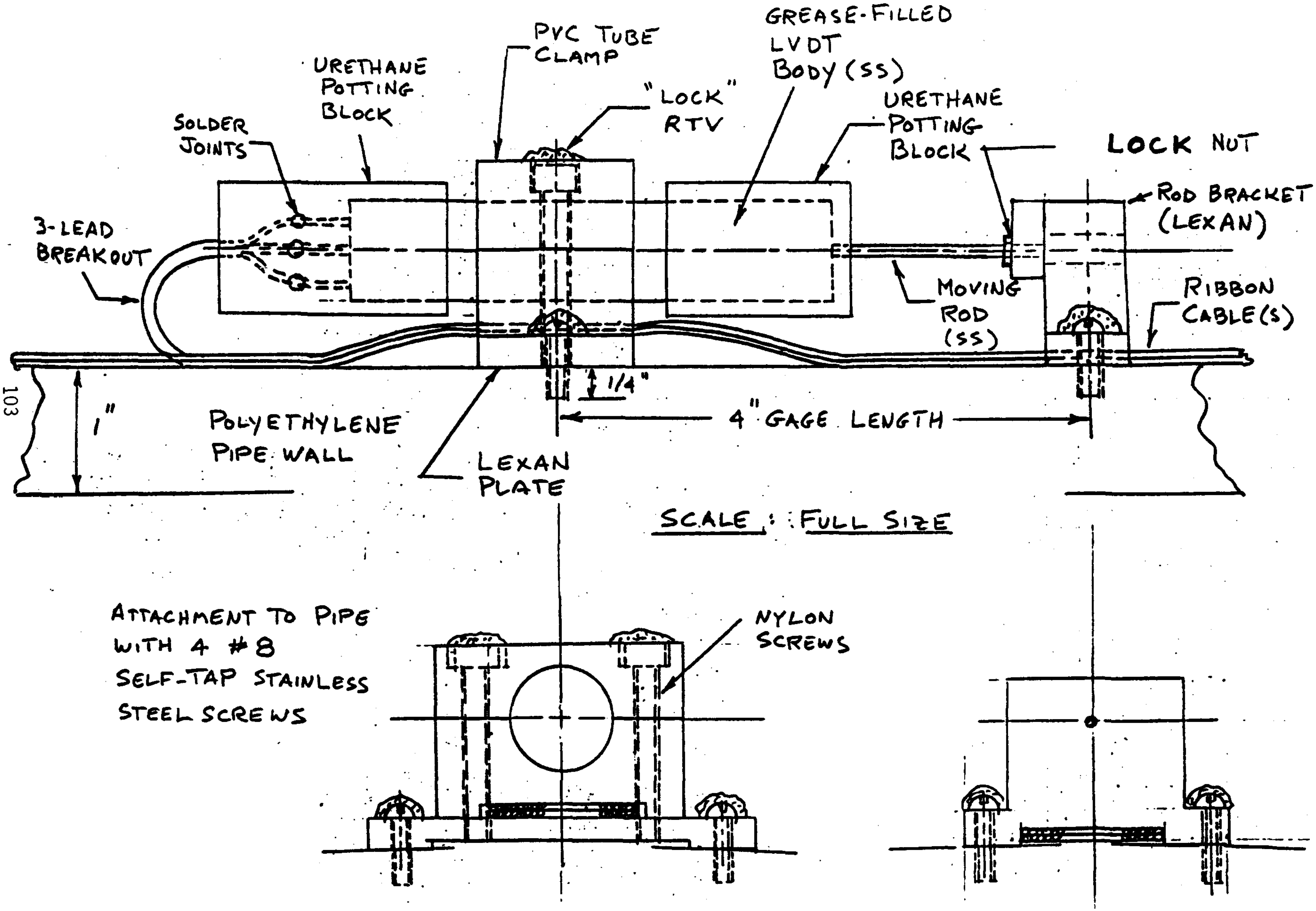


FIGURE 1
HARNESS CONDUCTOR BRANCHING

FIGURE 2- TYPICAL LVDT INSTALLATION



103

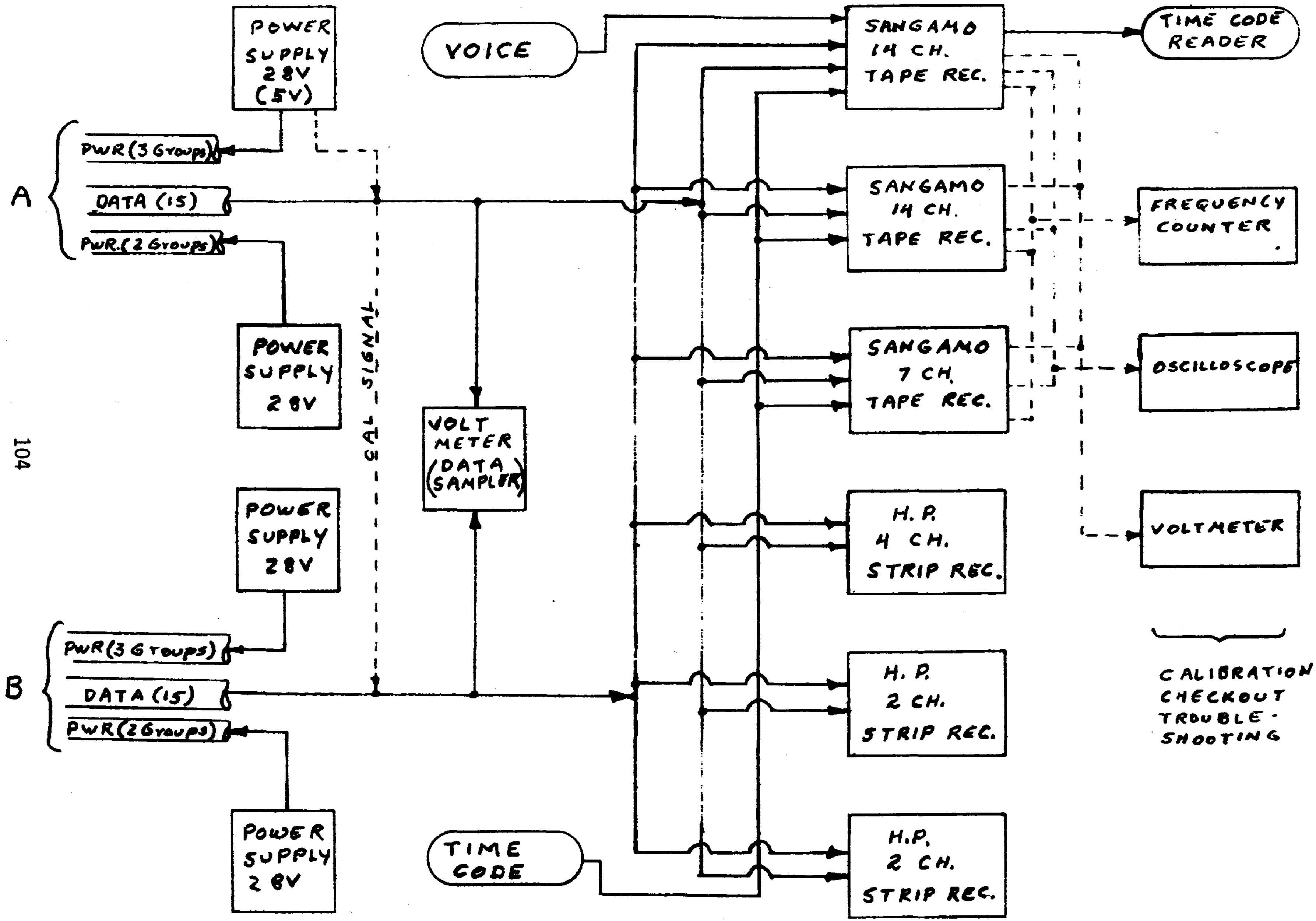


FIGURE 3 - SHIPBOARD DATA SYSTEM

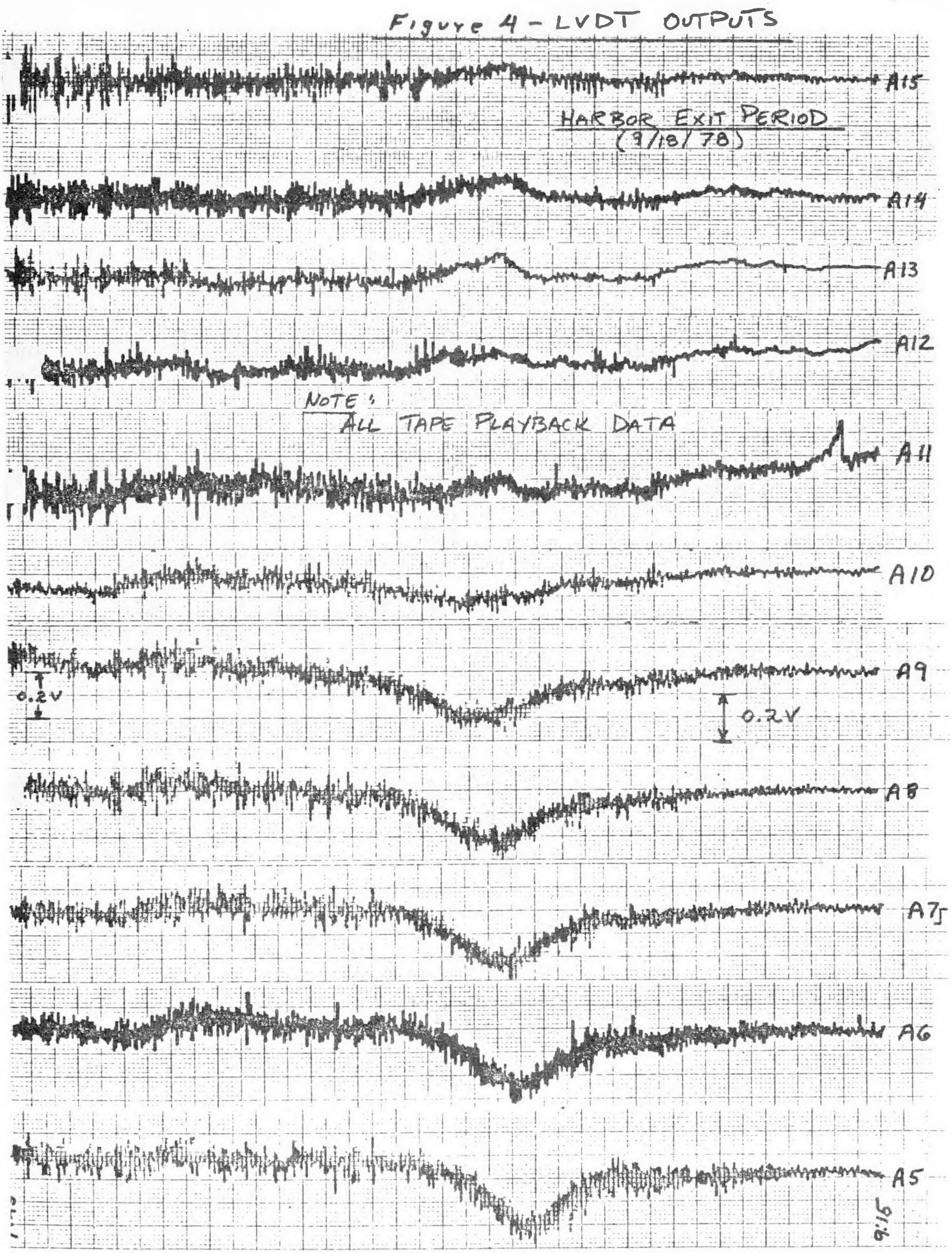
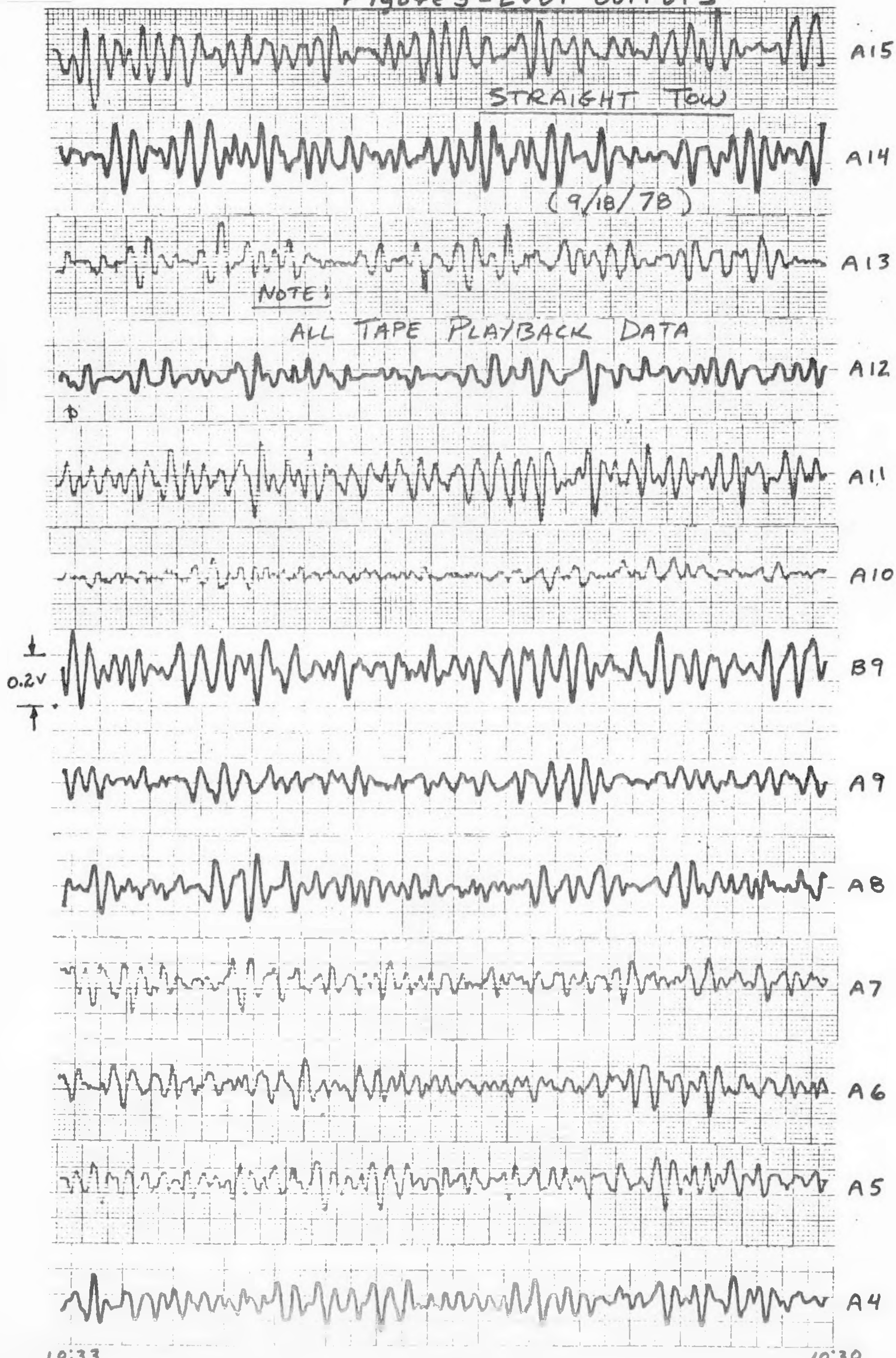


Figure 4 - LVDT OUTPUTS
HARBOR EXIT PERIOD
(9/18/78)
NOTE:
ALL TAPE PLAYBACK DATA
A15
A14
A13
A12
A11
A10
A9
0.2V
0.2V
A8
A7
A6
A5
9:15

Figure 5 - LVDT OUTPUTS



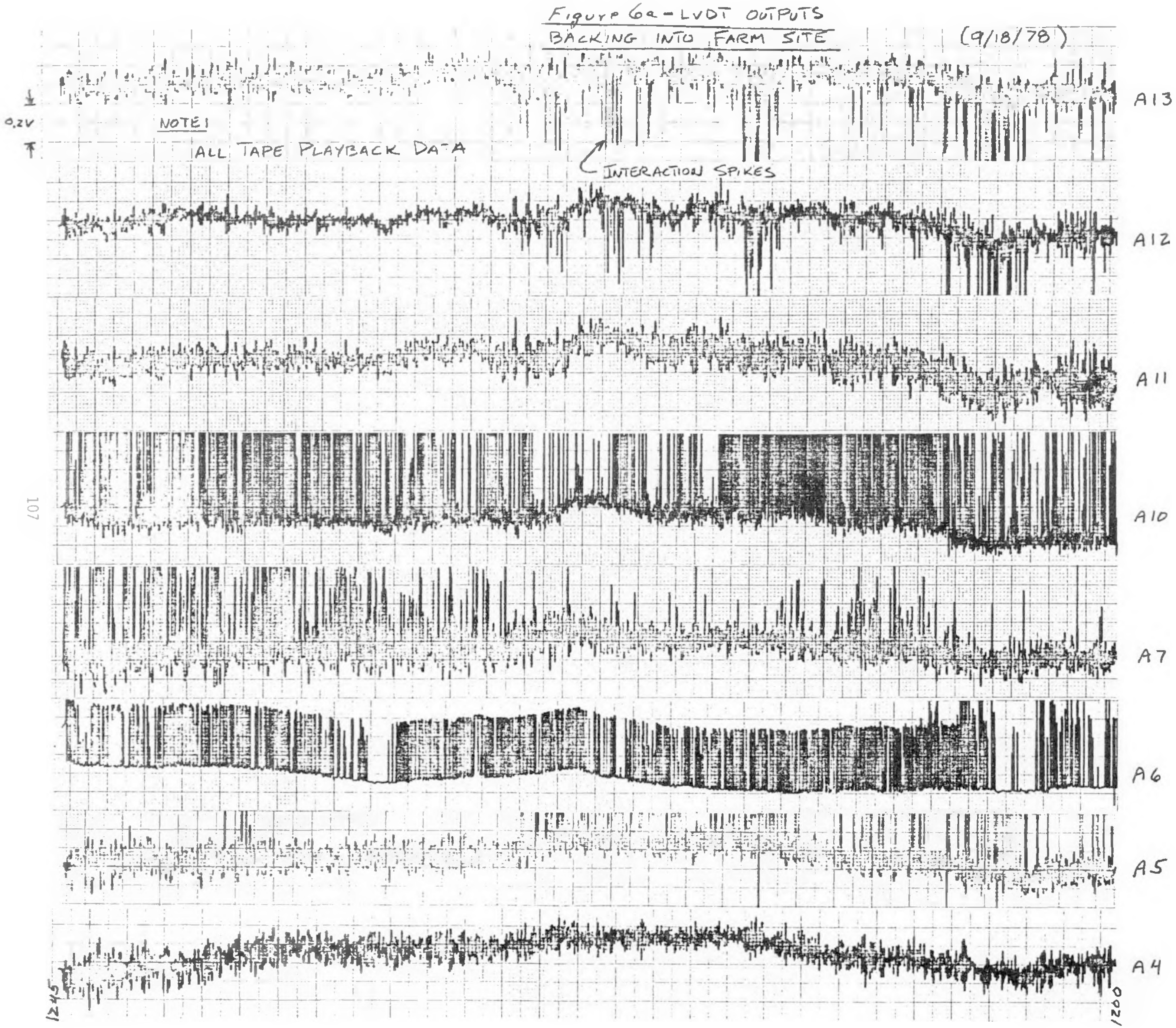


Figure 6a - LVDT OUTPUTS
BACKING INTO FARM SITE
(9/18/78)
0.2V
NOTE 1
ALL TAPE PLAYBACK DATA
INTERACTION SPIKES
A13
A12
A11
A10
A7
A6
A5
A4
1245
1200

Figure 6b - LVDT OUTPUTS
BACKING INTO FARM SITE (9/18/78)

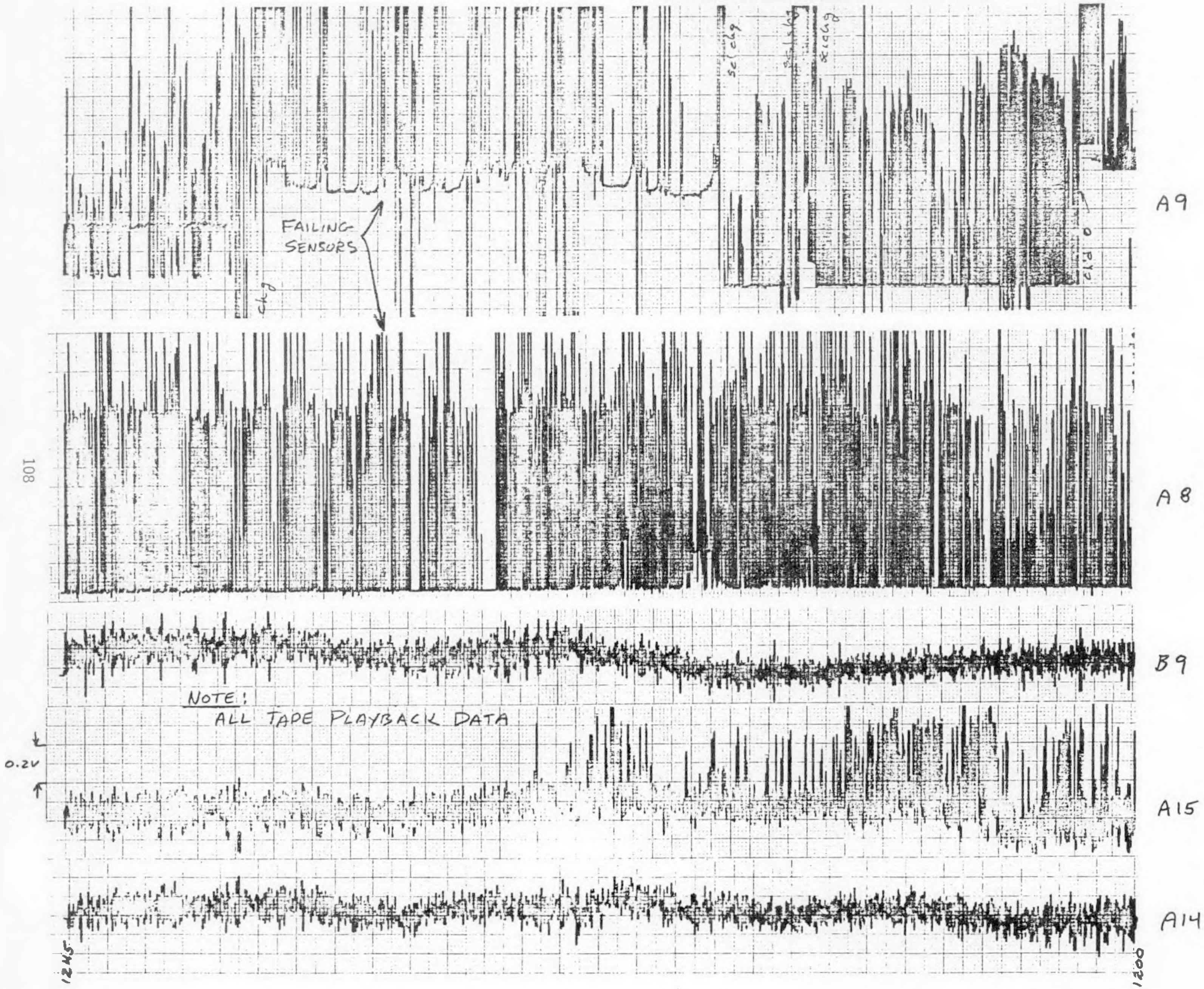
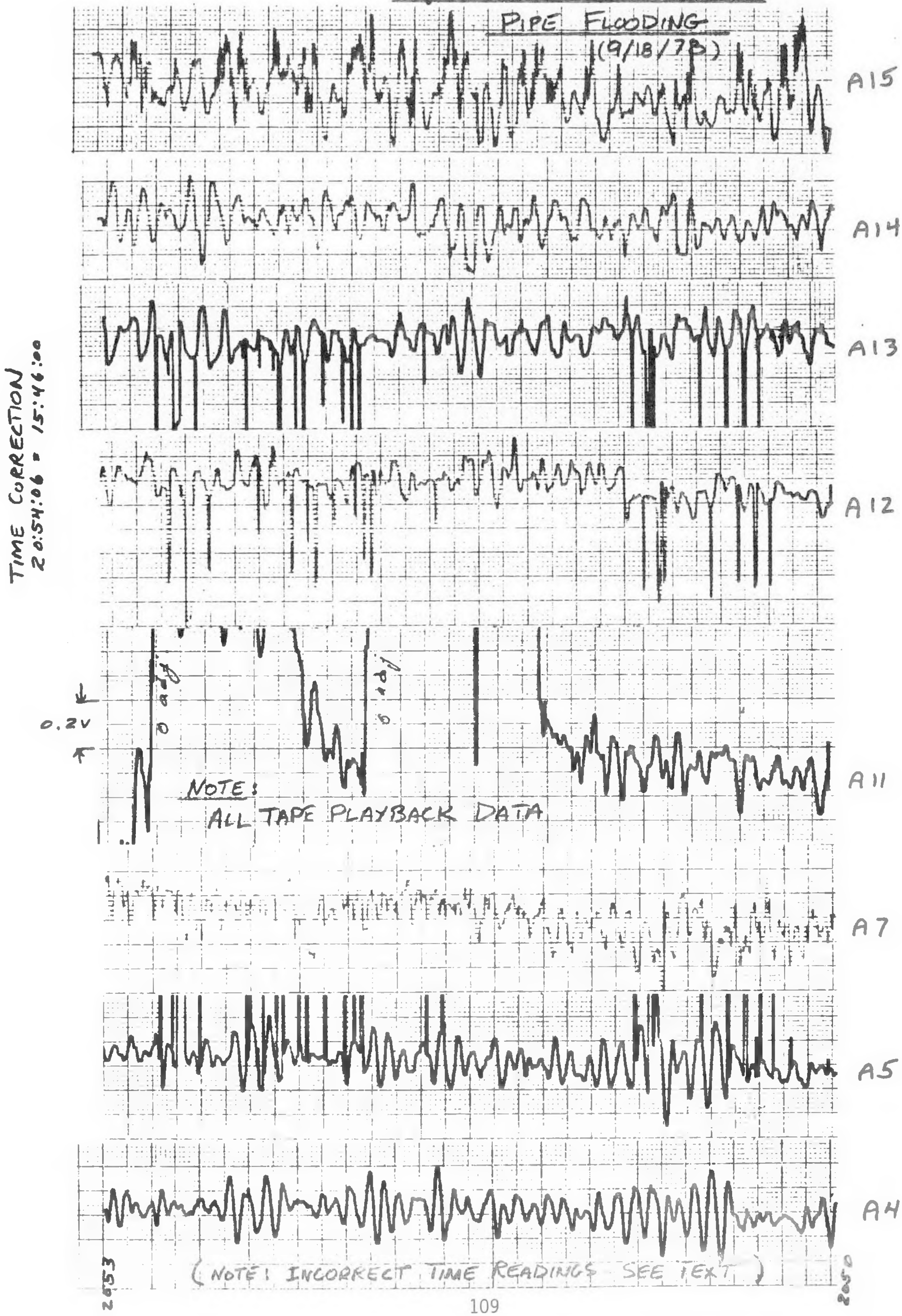


Figure 7- LVDT OUTPUTS



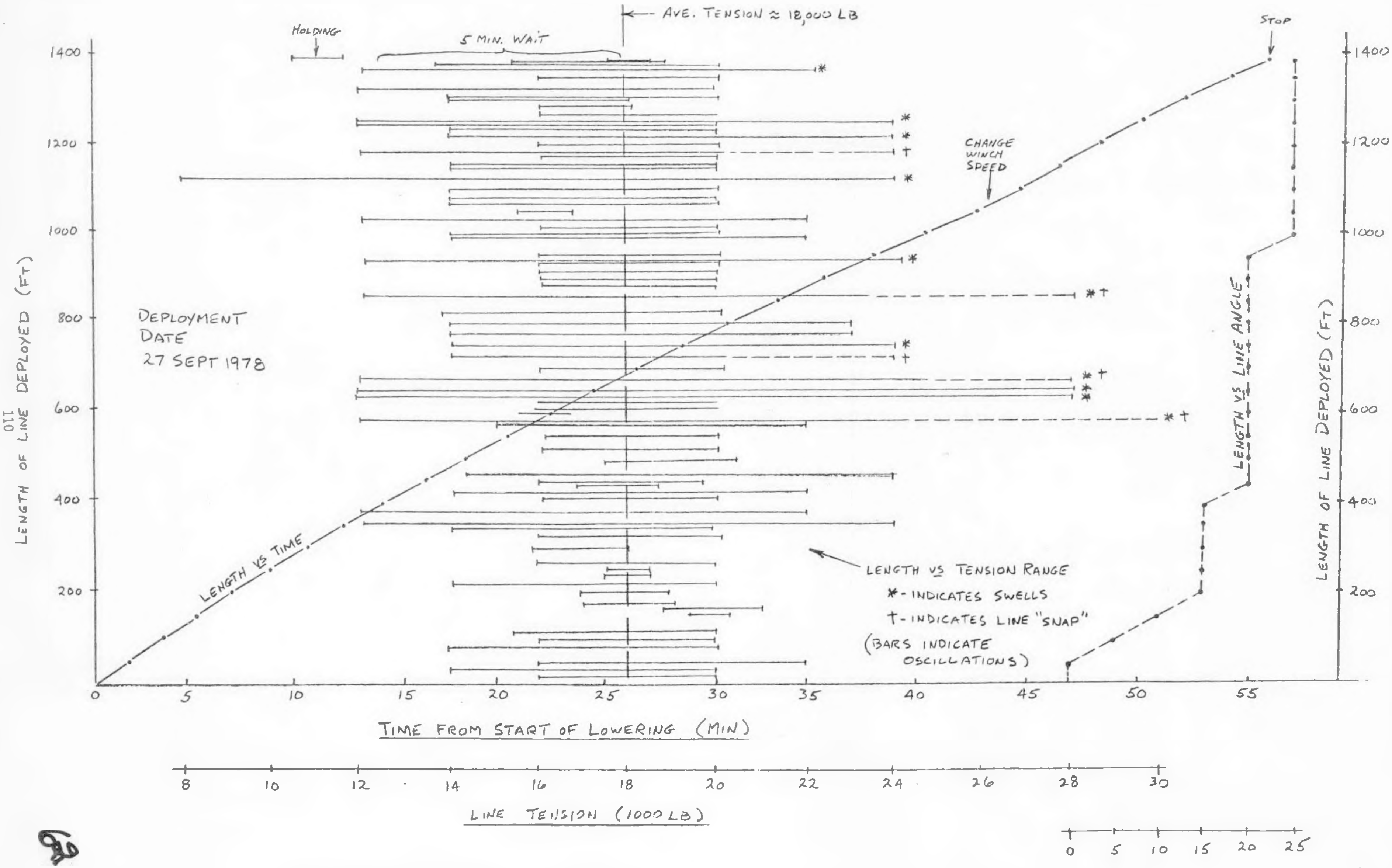


FIGURE 8 LOWERING LINE DATA

Appendix A - Data Recording Events/Chronologies

During the limited data scan, events as verbally annotated on voice tracks of magnetic tapes 1-1, 1-2, and 1-3 were documented in Tables A-1 - A-3. The tables also indicate the approximate footage from the start of the tape to the indicated time/event. No voice tracks were recorded on the other data tapes (Recorders #2 and #3) which were recorded simultaneously with the Recorder #1 tapes.

A review of the events on the 16 mm movie film was also conducted. The events on the films are logged in Tables A-4 and A-5 for the Lambert (outside vendor) and GE (Company photographer) reels. The time (minutes:seconds) of each event from the start of the reel is also indicated. The film speed is 24 FPS.

DC-DC LVDT

TRANS-TEK INCORPORATED

DISPLACEMENT TRANSDUCER DC-DC SERIES 240

3 TO 30 VOLT EXCITATION

FOR A DC VOLTAGE OUTPUT PROPORTIONAL TO DISPLACEMENT

- DC in, DC out
- Adjustable scale factor
- No phasing, harmonic or quadrature null problems
- Polarity protected
- Zero hysteresis
- Stepless output
- Excellent repeatability
- High output
- Up to 8″ range
- Extreme linearity
- Fast response
- Light weight

DESCRIPTION

The Trans-Tek Series 240 displacement transducer is an integrated package consisting of a precision linear variable differential transformer, a solid state oscillator, and a phase-sensitive demodulator.

The transducer is designed to combine in one small but rugged package the achievement of excellent linearity, infinite resolution, and high sensitivity. The phasing, quadrature null and harmonic problems often experienced with AC differential transformers are eliminated.

Input and output circuits are electrically isolated from each other and from the coil assembly housing, making them usable directly in floating or ground return systems. DC indicators, recorders, and control systems can usually be driven directly by the large DC output. The core, when displaced axially within the coil assembly, produces a voltage change in the output directly proportional to the displacement.

CONSTRUCTION

All materials have been selected carefully to achieve optimum performance. The stainless steel housings, coil assembly, oscillator-demodulator, and Teflon-insulated leads are carefully encapsulated in epoxy resin. Oscillator-demodulator components are individually selected to assure accuracy and reliability.

PRINCIPLE OF OPERATION

The oscillator converts the DC input to AC, exciting the primary winding of the differential transformer. Voltage is induced in the secondary windings by the axial core position. The two secondary circuits consist of a winding, a full-wave bridge, and an RC filter.

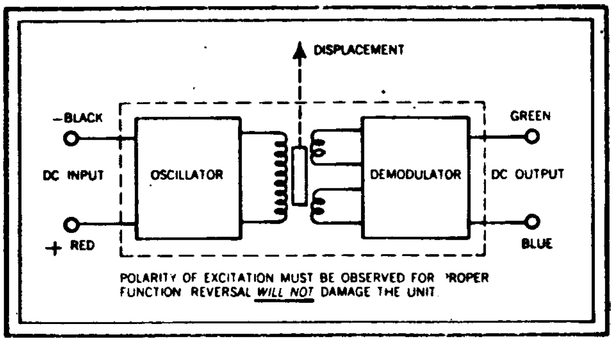
The circuits are connected in series opposition so that the resultant output is a DC voltage proportional to core displacement from the electrical center. The polarity of the voltage is a function of the direction of the core displacement with respect to the electrical center.

APPLICATION

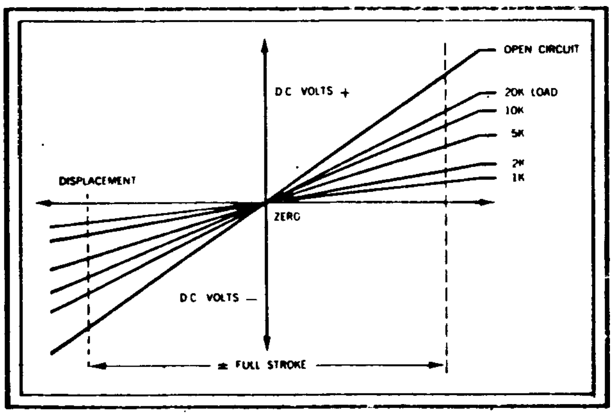
A Series 240 transducer can be used to measure physical functions which can be translated into a linear displacement. Typical applications include servo position feedback, sensor for pressure transducers, strain measurement in structural members, automatic gauging, and machine control.

INSTALLATION

A Series 240 transducer can be mounted by clamping around the housing to a physical reference point. The dynamic member to be monitored is coupled to the threaded connecting rod of the core assembly or to the optional core by means of a threaded extension rod. Mounting hardware should be of nonmagnetic materials such as brass, aluminum, or 300 series stainless steel.



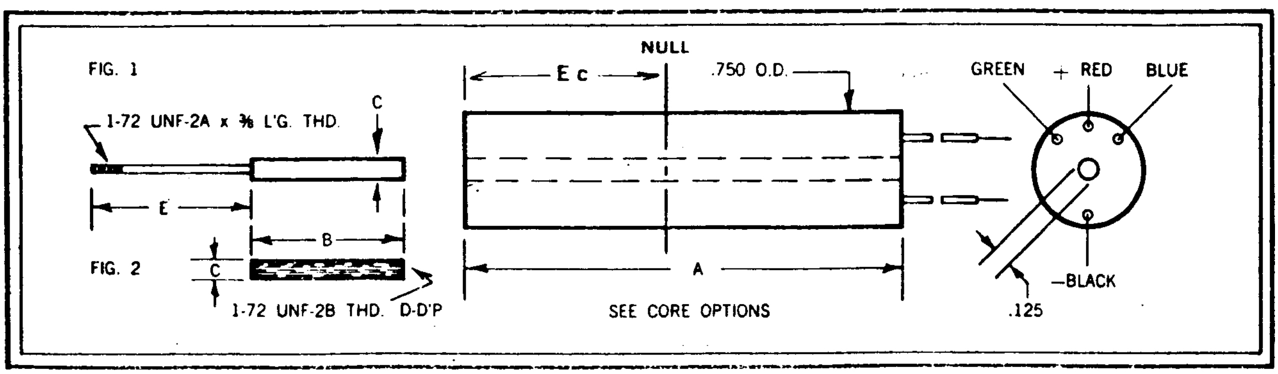
CIRCUIT DIAGRAM



DISPLACEMENT VS. OUTPUT DIAGRAM

CORE OPTIONS

Model	Option	Fig.	Core Pt. No.	B	C	D	E
240-000	Std.	1	C04-000	.562	.120	—	1.90
240-000	1	1	C04-001	.562	.099	—	1.90
240-000	2	2	C05-002	.562	.120	thru	—
240-000	3	2	C05-003	.562	.099	thru	—
241-000	Std.	1	C04-004	.750	.120	—	1.90
241-000	1	1	C04-005	.750	.099	—	1.90
241-000	2	2	C05-009	.750	.120	3/16	—
241-000	3	2	C05-010	.750	.099	3/16	—
242-000	Std.	1	C04-010	1.75	.120	—	1.90
242-000	1	1	C04-006	1.75	.099	—	1.90
243-000	Std.	1	C04-011	1.87	.120	—	2.40
243-000	1	1	C04-007	1.87	.099	—	2.40
244-000	Std.	1	C04-012	2.00	.120	—	3.20
244-000	1	1	C04-008	2.00	.099	—	3.20
245-000	Std.	1	C04-013	3.50	.120	—	5.20
245-000	1	1	C04-009	3.50	.099	—	5.20
246-000	Std.	1	C04-014	3.50	.120	—	8.40
246-000	1	1	C04-015	3.50	.099	—	8.40



DIMENSIONAL DIAGRAM

ELECTRICAL SPECIFICATIONS

Model Number	240-000	241-000	242-000	243-000	244-000	245-000	246-000
Range, working	±0.050	±.100	±.250	±.500	±1.00	±2.00	±3.00
Max. usable	±0.075	±.150	±.375	±.750	±1.50	±2.75	±4.00
Input, volts DC	3.0 Min. to 30 Max.						
Output, full scale DC ± (nom.) open circuit @ 3 V. input	0.55	1.0	0.8	1.4	2.0	2.0	1.5
@ 6 V. input	1.2	2.1	1.6	3.0	4.3	4.0	3.1
@ 15 V. input	3.0	5.4	4.2	7.5	10.8	10.0	7.8
@ 24 V. input	5.0	9.0	7.0	12.5	18.0	16.0	13.0
@ 30 V. input	5.9	10.7	8.3	14.8	21.4	20.0	15.4
Input current	2.8 ma @ 3 V. input to 52 ma @ 30 V. input						
*LINEARITY % FULL SCALE OVER TOTAL WORKING RANGE	±0.5	±0.5	±0.5	±0.5	±0.5	±0.5	±0.5
OVER MAX. USABLE RANGE	±1.0	±1.0	±1.0	±1.0	±1.0	±1.0	±1.0
Internal carrier Freq. Hz Nom. greater than	13000	12000	3600	3400	3200	1500	1400
% Ripple (RMS) nom.	0.7	0.7	0.8	0.8	0.8	1.0	1.0
Output impedance (ohms)	2500	3500	5200	5500	5600	5500	5600
Freq. Response 3 db down Hz	300	140	115	110	100	110	75
Temperature Range	−65° F. to +250° F.						
Resolution	Infinite						

PHYSICAL SPECIFICATIONS

Model Number	240-000	241-000	242-000	243-000	244-000	245-000	246-000
Coil assembly (length A)	0.87	1.12	3.21	3.71	4.71	8.21	10.52
Coil assembly (weight, grams)	22	28	70	80	104	180	220
Core assembly (weight, grams)	1.6	2.1	3.4	3.8	4.3	7.0	8.1
Termination all models	#22 AWG by 18″ long Teflon insulated leads						
E c	**0.34**	**0.46**	**1.44**	**1.69**	**2.19**	**3.94**	**5.09**

REPLACEMENT CORES

Model Number	240-000	241-000	242-000	243-000	244-000	245-000	246-000
Replacement core Part Numbers	C04-000 C04-001 C05-002 C05-003	C04-004 C04-005 C05-009 C05-010	C04-006 C04-010	C04-007 C04-011	C04-008 C04-012	C04-009 C04-013	C04-014 C04-015

**Linearity is defined as the deviation from the best straight line passing thru zero, is less than 0.5% of the total full scale output over the total working range. ex. (Model 246-000 total working range is 6.00 inches) or 1% of the total usable range.*

DC-DC LVDT

MODIFICATIONS

Transducers for special applications are available. Consult Trans-Tek, Inc. on your particular requirements.

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All Trans-Tek transducers are warranted against defective materials and workmanship for one year.

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All specifications and prices subject to change without notice. Contact Trans-Tek for quantity discount prices available on all models and on combined orders. (For areas beyond the United States . . . contact the international representative.)

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TRANS-TEK INCORPORATED

Route 83, Ellington, Connecticut 06029

SECTION II

INOCULUM DEVELOPMENT

MARINE BIOMASS PROGRAM

INOCULUM DEVELOPMENT PHASE

JANUARY 1, 1978 - DECEMBER 31, 1978

SUMMARY

The Inoculum Development Phase of the Marine Biomass Program has as its prime objective the development of an optimized marine derived anaerobic culture for the conversion of kelp to methane gas. Implicit in this objective is developing a significant understanding of the microbiological and biochemical events occurring in and responsible for this transformation to be able to effectively control and manipulate the process.

Consistent with this objective, the following major significant accomplishments were obtained by this laboratory during this reporting period:

- Stock and baseline kelp digesters established from marine sources at the initiation of this program have been maintained to serve as controls, as microorganism isolation sources and as sources of cultures for manipulative experimentation.

- A preliminary study was completed on the effect of temperature (~24°C) on methane generation from kelp using a marine derived inocula which indicated that methane yields at ambient (~24°C) were equal to those obtained at 37°C.

- Microbial strains utilizing the kelp constituents mannitol and algin were characterized and their growth and metabolic capabilities defined. The data indicate that these substrates are completely utilizable and theoretically convertable to methane.

- A variety of methanogenic enrichments utilizing exclusively acetate and other low molecular fatty acids have been obtained and isolation attempts are in progress.

- Enrichments capable of completely degrading Walseth cellulose preparations within 24 hours have been obtained. Predominant strains appear to be anaerobic Cytophaga-like organisms and do not readily form colonies, making isolation/purification difficult.

- Two 70-liter digesters have been designed and fabricated. One system has checked out and has been shipped to IGT. The second system is in evaluation and is scheduled for shipment to WRRC.

- Salt tolerance tests have shown that all isolates tolerate up to 7% salt without any apparent change in growth/metabolic patterns indicating potential ability to function in digesters with high solids loadings.

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MARINE BIOMASS PROGRAM

INOCULUM DEVELOPMENT PHASE

FINAL REPORT

JANUARY 1, 1978 - DECEMBER 31, 1978

I. INTRODUCTION

The Inoculum Development Phase of the Marine Biomass Program was initiated with the objective of developing an optimized alternate culture for the bioconversion of kelp to methane gas. The marine environment was chosen as the source of these microorganisms due to the anticipated compatibility of marine strains with digester environmental constraints and to the natural association of these forms with kelp in the aquatic habitat.

The initial thrust of the program was directed towards the isolation and study of those organisms responsible for the degradation and utilization of the major kelp constituents. The program scope has since been expanded and modified to include fundamental studies of the process rate limiting steps of cellulose degradation and methanogenesis from acetate and to studies associated with temperature effects on digestion.

This report will detail the results obtained during the last quarter of 1978 in the conduct of this program. In addition, certain aspects which have been completed and reported earlier have been included *in toto*, while other sections have been expanded and updated as required.

II. AMBIENT TEMPERATURE DIGESTION OF KELP

The anaerobic digestion of kelp to methane has been shown to be a slightly exothermic reaction (~250-350 Btu/lb volatile solids reacted; Klass and Ghosh, 1977) requiring energy (heat) to be put into the system in order to maintain a reaction temperature of 35-37^{o}C, the temperature at which most digester systems have been shown to operate optimally (i.e., sewage digesters). Digestion at ambient temperature would be particularly attractive as it would result in a net system energy increase. Preliminary data obtained with a solely marine derived culture has indicated that ambient temperature (i.e., ~24°C) operation without sacrifice in methane yield may be feasible. Gas yield data for digesters operating at ambient and 37°C temperatures is presented in Tables 1 and 2 and shown graphically in Figures 1 and 2. Corresponding pH values are given in Table 3. Table 4 provides a summation of these data and shows that under the conditions employed (DT = 2 days, alternate day feeding at ~0.1 lb VS/ft^3 of digester volume) gas yields obtained at 24°C is statistically greater than that achieved at 37°C. This is true for both total gas output and methane yield. These data may reflect a basic difference between marine and sewage derived inocula and suggest that additional experiments be performed under a variety of defined conditions in order to substantiate these findings.

III. METHANOGENESIS

During April of this year, a meeting was held to review the status of the Inoculum Development Phase of the Marine Biomass Program and to provide major guidelines as to the direction the research effort should pursue. This meeting was attended by A. J. Bryce (Technical Director, Marine Biomass Program), R. W. Makinen (GE-RESD), and Drs. R. Brooks (G. E. Corporate Research and Development Center), D. Chynoweth (IGT), J. G. Ferry (VPI, Anaerobe Laboratory), K. K. Jain (GE-RESD, and J. R. Forro (GE-RESD).

As a result of this meeting, a redirection of the research effort was initiated, with emphasis being placed upon two major areas - acetate conversion to methane and cellulose degradation.

The first area of research concerns what is thought to be the rate limiting step in methanogenesis - the conversion of acetate to methane. Acetete, which arises as an end product of metabolic activity of a large number of microbial species and is the foremost intermediate in anaerobic digestion, is the prime substrate for methanogenic activity (H_2 and CO_2 being secondary). Radioactive tracer studies have shown that the methyl group of acetate is converted directly to methane and that 70-73% of the methane gas in a digester arises via this pathway.

Previous studies have shown that as loading rates are increased and/or detention times decreased in kelp digesters, failure associated with the accumulation of acid (acetate) and

TABLE 1

GAS DATA FOR 37°C BASELINE KELP FERMENTER

(MINIFERMENTER #6)

Feed Date	% Methane	SCF Gas/lb VS Added CH_4	SCF Gas/lb VS Added Total	Remarks
1/2	51	4.22	6.69	
1/4	49	2.60	6.63	
1/9	48	2.60	5.07	
1/11	50	3.57	6.75	
1/13	48	1.58	2.78	
1/16	46	1.63	2.64	Increased feeding to 0.13 lb VS/ft^3
1/18	52	4.42	7.79	
1/21	45	0.32	1.14	
1/23	48	2.64	5.44	
1/25	44	1.72	3.11	Adjusted pH
1/27	50	2.05	3.67	
1/30	52	2.49	4.58	
2/1	54	2.82	4.95	
2/6	49	2.70	5.15	
2/8	49	0.85	1.73	Some air in system
2/10	50	2.09	3.77	
2/13	47	1.28	3.04	
2/15	49	3.10	6.44	
2/17	51	2.01	3.45	
2/21	51	3.52	6.34	
2/24	52	2.59	4.70	
2/27	52	2.18	4.67	
3/1	52	3.14	6.14	
3/3	52	1.71	2.64	Agitator stopped during weekend
3/6	55	3.38	6.62	
3/8	54	3.11	5.32	Adjusted pH
3/10	57	2.74	4.35	
3/13	54	2.21	4.92	
3/15	54	2.04	4.00	
3/17	57	2.62	4.11	
3/20	56	2.57	5.11	
3/22	62	2.55	4.03	
3/27	55	1.02	3.19	

TABLE 2

GAS DATA FOR AMBIENT TEMPERATURE KELP FERMENTER

(MINIFERMENTER #8)

Feed Date	% Methane	SCF Gas/1b VS Added) CH_4	Total	Remarks
1/4	54	3.39	6.28	
1/6	52	2.53	4.32	
1/9	53	2.38	4.43	
1/11	53	2.32	3.11	Adjusted pH
1/13	54	3.11	5.16	
1/16	50	1.43	3.38	Increased feeding to 0.13 lb VS/ft^3
1/18	54	3.58	6.18	
1/21	49	1.16	2.87	
1/23	52	2.80	4.21	Adjusted pH
1/25	52	2.14	4.25	Adjusted pH
1/27	52	3.17	5.73	
1/30	53	2.34	4.84	
2/1	54	3.41	6.07	
2/3	49	2.12	3.77	
2/6	48	2.15	4.49	Agitation stopped during night.
2/8	49	2.46	4.69	
2/10	50	3.49	6.05	Agitation stopped during weekend.
2/13	47	1.62	3.84	
2/15	52	3.46	6.56	
2/17	56	4.55	6.54	
2/21	55	2.96	6.05	
2/24	55	3.12	5.49	
2/27	57	3.08	6.25	
3/1	53	2.28	4.39	
3/3	58	3.99	5.93	
3/6	57	2.94	--	
3/8	56	2.27	--	Adjusted pH
3/10	58	3.82	6.63	
3/13	58	2.69	5.11	
3/15	56	2.76	5.53	Agitation stopped during night.
3/17	58	4.12	7.18	
3/20	53	1.66	3.42	
3/22	51	3.80	6.23	
3/27	55	1.87	3.76	

Figure 1. MINIFERM 6 (37°)
SCF METHANE AND TOTAL GAS
PER POUND VS ADDED

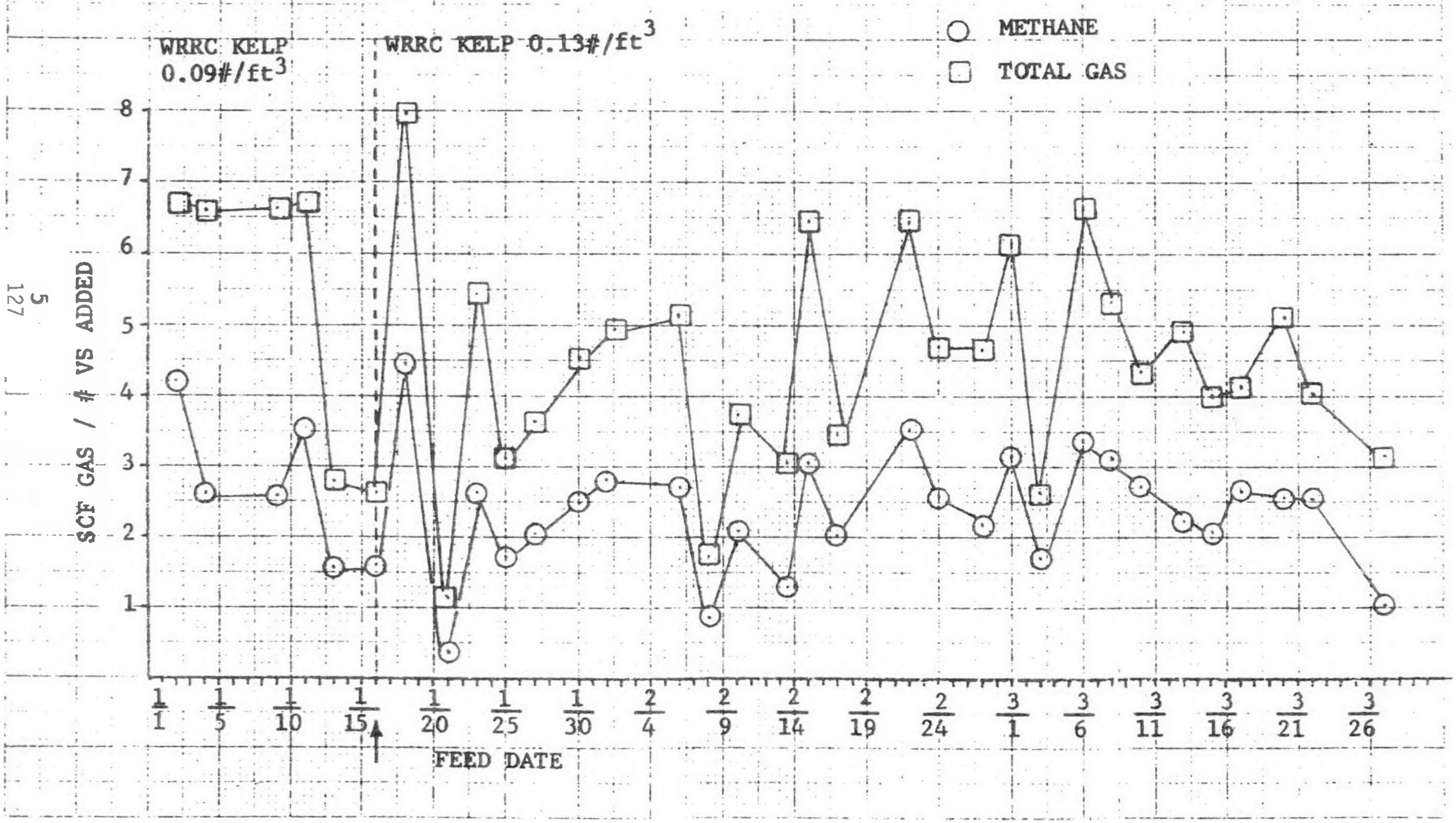


Figure 2. MINIFERM 8 (AMBIENT TEMPERATURE)
SCF METHANE AND TOTAL GAS
PER POUND VS ADDED

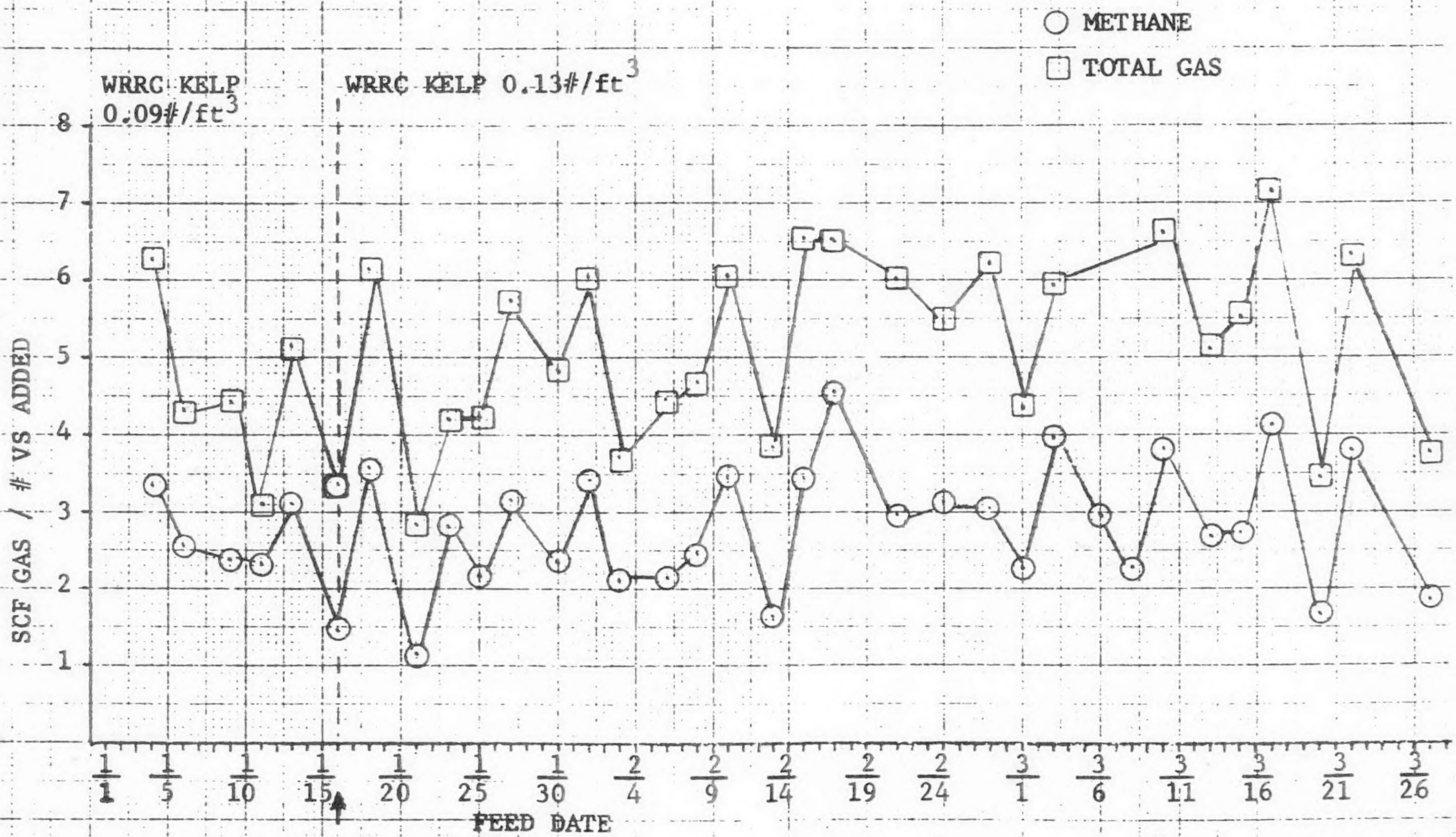


TABLE 3

pH DATA FOR RAW KELP FERMENTERS

Date	Miniferm[(1)]	Miniferm 8[(2)]
1/2	6.6	6.5
1/4	6.9	6.7
1/6	6.6	6.4*
1/9	6.6	6.7
1/11	6.7	6.5*
1/13	6.6	6.6
1/16	6.6	6.7
1/18	6.6	6.6
1/21	6.7	6.6
1/23	6.6	6.4*
1/25	6.6	6.5*
1/27	6.7	6.6
1/30	6.7	6.6
2/1	6.6	6.5
2/8	6.6	6.5
2/15	6.6	6.5
2/17	6.6	6.4*
2/21	6.7	6.6
2/24	6.7	6.6
3/1	6.6	6.5
3/3	6.7	6.5
3/6	6.6	6.5
3/8	6.5*	6.4*
3/10	6.9	6.6
3/13	6.7	6.6
3/15	6.7	6.6
3/17	6.6	6.5
3/20	6.7	6.5
3/24	6.7	6.7
3/27	6.8	6.8

*Adjusted pH

(1) 37°C

(2) Ambient Temperature

TABLE 4

COMPARISON OF RAW KELP DIGESTION AT AMBIENT AND 37°C TEMPERATURES*

(DT = 20 DAYS)

Parameter	Ambient (24-26°C)	37°C
CH_4 (SCF/lb VS Added)	2.96	2.74
Total Gas (SCF/lb VS Added)	5.32	5.15
% CH_4	53.	52.

*These data are averages of >50 samples taken over period 11/4/77 - 3/31/78.

NOTE: Difference of 0.22 statistically significant at 95% confidence level.

reduced methane yields is noted. This failure is not a result of acidogenic activity *per se*, but rather appears to result from the inability of the system to handle the increased acid loading due to the acetate utilizing bacteria being in insufficient numbers or activity.

The approach to the examination of this problem that was formulated as the result of this meeting basically entails the development of large scale (i.e., >1 liter) acetate to methane enrichments from existing mixed acid methanogenic food chains, isolation of acetate utilizing methanogens, studying the kinetics of acetate conversion and developing sufficient populations of these enrichments/pure cultures which can be used to augment existing acetate utilizing methanogens in standard kelp digesters or in mixed substrate fermenters (i.e., mannitol + algin + cellulose). In this manner, the kinetics of kelp digestion and of acetate production/utilization may be studied under non-rate-limiting conditions and under conditions where kelp digestion itself may be the rate-limiting step. It may be then possible to temporarily or permanently (should the cells become established) lower the detention time and/or substrate loading and test the validity of the projected target goals of a 6-day retention time and a loading of 0.45 lb VS/ft^3.

To this end then, a series of methanogenic enrichments were established using a variety of source material as inocula, and a variety of different selective media. These have been carried through several transfers and as described below, some preliminary kinetic data on their performance has been obtained.

A. METHANE PRODUCTION - BATCH ENRICHMENT STUDIES

As part of the methanogen enrichment study, batch cultures of two enrichments (11E and MF8) were established in BWS and FAS media (described previously) with incubation at room temperature ~24°C) for a period of a month. Total methane gas produced was determined at 5-day intervals in order to establish both baseline methane generation rates and yields. These data are presented in Table 5 and are graphically displayed in Figure 3. Clearly, the two enrichments examined are distinct in terms of their ability to produce methane in a mixed acid medium (BWS) and although their performance in an acetate

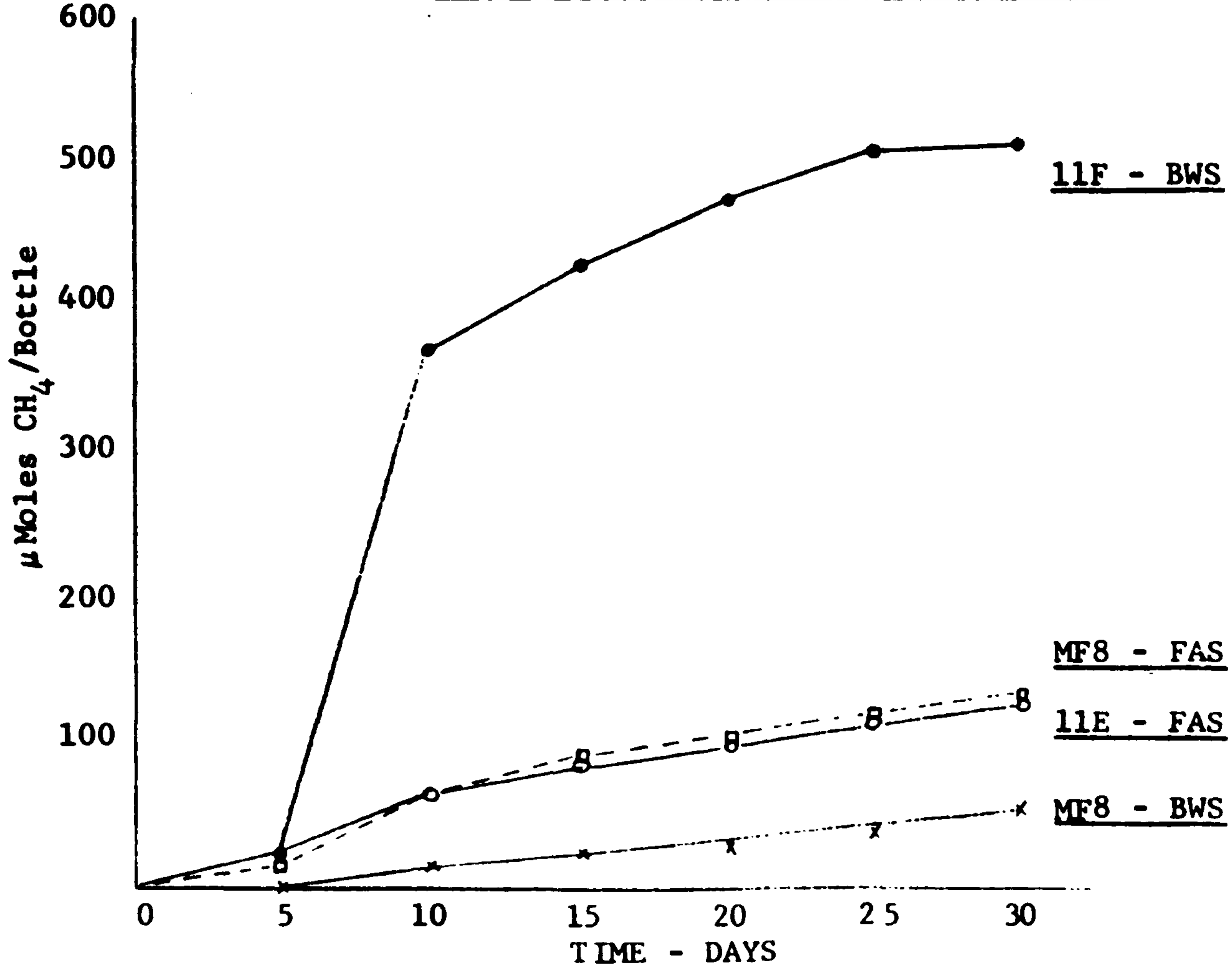
TABLE 5. PRODUCTION OF METHANE IN SELECTED MEDIA BY TWO METHANOGENIC ENRICHMENTS

MEDIUM*	DAY	μ MOLES CH_4/CULTURE**	
		11E16	MF8
BWS	5	21.6	0
	10	372.0	16.1
	15	431.7	25.8
	20	473.7	31.6
	25	518.7	39.8
	30	520.3	57.4
FAS	5	21.7	14.1
	10	68.9	70.7
	15	90.6	95.0
	20	104.0	108.2
	25	115.6	120.3
	30	130.1	134.0

* BWS - MEDIUM OF BALCH AND WOLFE + 3% NaCl
FAS - MEDIUM OF FERRY *et al* + 3% NaCl

** AVERAGE METHANE IN DUPLICATE CULTURES, 160 ml SERUM BOTTLES CONTAINING 100 ml MEDIA

Figure 3. PRODUCTION OF METHANE IN SELECTED MEDIA BY TWO METHANOGENIC ENRICHMENTS



medium (FAS) is quite similar, it suggests these enrichments represent different microbial consortiums. This is supported by the acid utilization and methane production data obtained during transfer studies.

B. FEEDING TRIAL EXPERIMENT

The objective of this study was to determine the effect of varying the feeding frequency, the feeding volume on the utilization of VFA's, and the subsequent production of methane by two methanogenic enrichment cultures. The feeding frequencies were 5, 10, and 20-day intervals, with volume changes of 25 and 50 percent of the medium volume. The head space was purged with N_2/CO_2 (80:20) after each feeding. Two different media were examined for each enrichment. BWS is the medium of Balch and Wolfe (1976) modified to contain 3% NaCl, 5 ml filter sterilized vitamin solution of Wolin et al. (1963), and with the following substitutions: tryptone for trypticase, propionic acid for α-methyl butyric acid, and valeric acid for isovaleric acid. FAS is the acetate medium of Ferry et al. (1974) modified to contain 3% NaCl. All incubations were at room temperature. Gas pressure was determined manometrically. Methane and CO_2 were quantitated by gas chromatography, with reported values corrected to 760 mm Hg and 60°F. VFA's were determined chromatographically using ether extracts (Anaerobe Laboratory Manual, VPI Anaerobe Laboratory, VPI, Blacksburg, Va. 1975), a SP1220 column, a thermal conductivity detector, and a temperature program operational mode. This procedure was utilized in place of the standard procedures as it allows detection and quantitation of all VFA's of interest including formic acid.

Tables 6-A to D summarize the methane and VFA data obtained in this study. For simplicity, VFA data is presented in terms of % change (+ or -) per feeding period and only those acids with large fluctuations are shown

This study produced one major, unexpected result. All VFA's from acetic to caproic were found to be produced at significant levels by both enrichments under all conditions examined. Thus the levels of all volatile

TABLE 6. EFFECT OF FEEDING FREQUENCY AND VOLUME ON METHANE PRODUCTION AND VFA UTILIZATION BY METHANE ENRICHMENTS

A. ENRICHMENT 11E IN BWS

FEEDING FREQUENCY (DAYS)	VOLUME CHANGE (%)	SAMPLE DAY	μMOLES CH_4 PER FEEDING	% CHANGE/FEEDING*				
				FORMIC	ACETIC	PROPIONIC	BUTYRIC	VALARIC
5	25	5	29.4	- 70	+ 62	+ 8	--	-24
		10	70.8	-100	+ 19	+ 2	+ 41	+ 3
		15	53.2	-100	+ 40	+24	+ 68	+29
		20	50.5	-100	+ 17	+ 8	+ 18	+ 1
		25	62.9	-100	+ 7	+11	+ 15	- 2
		30	63.5	-100	+ 21	+ 6	+ 24	- 8
		35	68.5	-100	+ 8	+ 9	+ 21	-14
	50	5	29.8	- 71	+ 84	+19	--	-16
		10	90.2	-100	+ 27	- 1	+ 55	-13
		15	89.7	-100	+ 52	+30	+134	+20
		20	97.5	-100	+ 74	+32	+109	+25
		25	114.9	-100	+ 11	+10	+ 46	- 9
		30	113.0	-100	+ 18	+16	+ 87	-19
		35	133.5	-100	+ 37	+12	+105	-18
10	25	10	141.2	-100	+104	+34	--	- 1
		20	73.4	-100	+ 22	+13	+ 36	+ 9
		30	73.5	-100	+ 2	+ 4	+ 17	- 7
	50	10	75.0	-100	+127	+39	--	+ 1
		20	116.1	-100	+ 32	+20	+108	+22
		30	100.7	-100	+ 16	+12	+ 59	- 3

* A POSITIVE % CHANGE INDICATES ACID PRODUCTION, A NEGATIVE % CHANGE INDICATES CONSUMPTION.

TABLE 6. EFFECT OF FEEDING FREQUENCY AND VOLUME ON METHANE PRODUCTION AND VFA UTILIZATION BY METHANE ENRICHMENTS

B. ENRICHMENT MF8 IN BWS

FEEDING FREQUENCY (DAYS)	VOLUME CHANGE (%)	SAMPLE DAY	μMOLES CH_4 PER FEEDING	% CHANGE/FEEDING				
				FORMIC	ACETIC	PROPIONIC	BUTYRIC	VALARIC
5	25	5	--	-19	+32	+ 6	--	-27
		10	15.5	- 3	- 4	- 3	+157	- 7
		15	20.0	0	+13	+13	+ 98	+11
		20	18.1	- 5	- 4	0	+ 43	- 2
		25	17.7	+ 9	+30	+10	+ 67	+29
		30	23.3	- 7	+ 5	-10	+ 69	-28
		35	28.8	0	+ 8	+ 9	+ 36	+ 6
	50	5	--	- 8	+24	0	--	-25
		10	16.2	0	+10	- 4	+182	- 9
		15	18.0	+ 4	+21	+15	+156	+10
		20	20.5	0	+ 7	+ 9	+ 94	+ 2
		25	23.6	+18	+38	+46	+139	+26
		30	30.9	0	+17	- 9	+ 72	- 9
		35	37.9	-16	+ 9	-13	+ 75	-30
10	25	10	15.1	- 4	+40	+30	--	- 2
		20	16.7	-10	- 9	-12	+ 88	-17
		30	22.1	+ 7	+27	+29	+142	--
	50	10	15.2	- 1	+31	+17	--	-12
		20	16.5	+ 2	+ 5	0	+134	+ 2
		30	29.9	+ 5	+33	+24	+126	+ 6

TABLE 6. EFFECT OF FEEDING FREQUENCY AND VOLUME ON METHANE PRODUCTION AND VFA UTILIZATION BY METHANE ENRICHMENTS

C. ENRICHMENT 11E IN FAS

FEEDING FREQUENCY (DAYS)	VOLUME CHANGE (%)	SAMPLE DAY	μMOLES CH_4 PER FEEDING	% CHANGE/FEEDING ACETIC	PROPIONIC	BUTYRIC
5	25	5	24.7	+54	--	--
		10	35.3	+ 9	+ 39	+ 30
		15	35.8	+28	+ 57	+ 47
		20	46.5	+16	+ 43	+ 68
		25	29.9	+ 4	+ 34	+ 37
		30	31.7	+ 5	+ 43	+ 47
		35	31.0	+ 4	+ 72	+ 31
	50	5	18.8	+51	--	--
		10	44.1	+17	+125	+ 47
		15	47.9	+39	+112	+104
		20	42.2	+32	+110	+103
		25	48.7	+21	+106	+136
		30	45.4	+12	+ 78	+107
		35	42.3	+14	+ 96	+103
10	25	10	36.0	+78	--	--
		20	30.9	0	+ 33	+ 22
		30	31.7	+25	+102	+ 42
	50	10	40.5	+86	--	--
		20	40.9	+10	+ 86	+ 71
		30	46.3	+42	+151	+119

D. ENRICHMENT MF8 IN FAS

FEEDING FREQUENCY (DAYS)	VOLUME CHANGE (%)	SAMPLE DAY	μMOLES CH_4 PER FEEDING	% CHANGE/FEEDING ACETIC	PROPIONIC	BUTYRIC
5	25	5	9.8	+54	--	--
		10	30.5	+11	+ 44	+ 56
		15	42.8	+27	+ 55	+ 15
		20	44.5	+ 7	+ 34	+ 33
		25	47.4	+38	+ 57	+ 36
		30	47.2	- 7	+ 22	+ 24
		35	50.3	+13	+ 28	+ 10
	50	5	5.1	+62	--	--
		10	42.4	+24	+126	+125
		15	56.7	+33	+104	+ 58
		20	49.1	+21	+105	+107
		25	65.7	+34	+ 85	+ 43
		30	66.6	+23	+134	+138
		35	67.1	+30	+101	+ 54
10	25	10	25.4	+86	--	--
		20	37.7	- 1	+ 36	+ 25
		30	44.4	+35	+ 75	+ 38
	50	10	25.4	+89	--	--
		20	45.7	+21	+106	+ 92
		30	55.8	+37	+131	+150

acids initially present in a given culture increased. The most likely source of these acids is via the conversion of the amino acids supplied by the tryptone and yeast extract. The level of non-volatile acids (i.e., succinate, lactate, etc.) in the medium has not yet been determined, but will be in the immediate future as these are also likely to be produced.

As a result of these findings, effort was placed on attempting to significantly reduce or eliminate the tryptone/yeast extract from these media formulations. Preliminary data indicate that these enrichment cultures require yeast extract, but that tryptone can be eliminated from these media without loss in methane production capacity. Whether yeast extract components are converted into VFA's has yet to be determined.

The findings reported here also have a major implication on possible interpretations of literature reports describing the stimulatory effect of large quantities of yeast extract (and other materials) on methane production by mixed cultures. Since none of the authors specifically looked at the VFA levels during their studies, they may have been observing a substrate effect, not a trace requirement effect.

In this study, iso-valeric, iso-caproic, and caproic acids were also present in significant levels, but were not quantitated as standards were not immediately available. They will be quantitated in all future studies.

Formic acid was completely utilized by enrichment 11E, and was essentially untouched by enrichment MF8. Valeric acid in BWS with enrichment 11E and MF8 was the only other acid exhibiting a net consumption during this study.

Methane production per feeding period increased above the initial levels, and appeared to reach a steady state by the end of the second feeding period. Only in the case of a 5-day feeding schedule with 11E cultured on BWS did a doubling of the feed volume result in a doubling of the methane yield. All other cases produced less than a doubling of methane per doubling of feed volume. In all instances, enrichment 11E produced more methane from BWS than from FAS, and enrichment MF8 produced the opposite pattern. This finding, in conjunction with the volatile acid data, suggests the microbial populations in the two enrichments are different.

C. METHANE PRODUCTION - CALCIUM ACETETE AND BUTYRATE ENRICHMENTS

In addition to the FAS and BWS methanogenic enrichments described above, cultures were established in the medium of Baresi *et al*. (1977) using either calcium acetate or calcium butyrate as substrate. After several transfers, these enrichments have been found to be very vigorous methane producers as shown in Tables 7 and 8, and graphically in Figures 4 and 5. The calculated rate of methane production by culture KM on acetate is about 1.9 mMoles/liter day, while rates from butyrate are about 4.6 and 2.7 mMoles/liter day for cultures MF8 and MF6 respectively. These cultures are still in the stage of development/stabilization and higher rates can be expected. For example, as shown in Table 9, small concentrations of yeast extract have been found to be stimulatory to culture MF9, raising the methane yield approximately 12-fold. Note also that substitution of a vitamin mixture for yeast extract had no stimulatory effect. Interestingly, culture KM was not further stimulated by the addition of yeast extract.

An alternate procedure is also being employed to enrich for acetate utilizing methanogens. Effluent from kelp digesters was transferred into stoppered serum bottles. Methane evolution was monitored with time and when the production rate was observed to decline significantly, a known quantity of acetic acid was addded to each culture. Gas production was noted to resume immediately indicating probable utilization of the added acid. This procedure has been followed several times with success as shown in Figure 6. These cultures which are being enriched for methanogens can then be utilized as material for isolation of important strains and for scale up (of mixed cultures) to study performance under steady-state digester conditions (i.e., pH controlled, continuous mode).

TABLE 7. GAS PRODUCTION BY CALCIUM ACETATE ENRICHMENT CULTURES

DAY	KM		MF-9	
	μMoles CO_2/ml	μMoles CH_4/ml	μMoles CO_2/ml	μMoles CH_4/ml
3	2.0	1.0	1.0	0.3
7	3.7	7.9	1.7	0.8
18	8.9	29.3	2.1	2.3

Gas yields are averages of duplicate cultures.

TABLE 8. GAS PRODUCTION BY CALCIUM BUTYRATE ENRICHMENT CULTURES

DAY	MF-6		MF-8	
	μMoles CO_2/ml	μMoles CH_4/ml	μMoles CO_2/ml	μMoles CH_4/ml
3	1.6	2.0	3.9	9.4
7	2.1	7.9	5.9	27.6
18	5.8	31.9	7.8	35.8

Gas yields are averages of duplicate cultures.

Figure 4. Methane Production by Two Calcium Acetate Enrichments

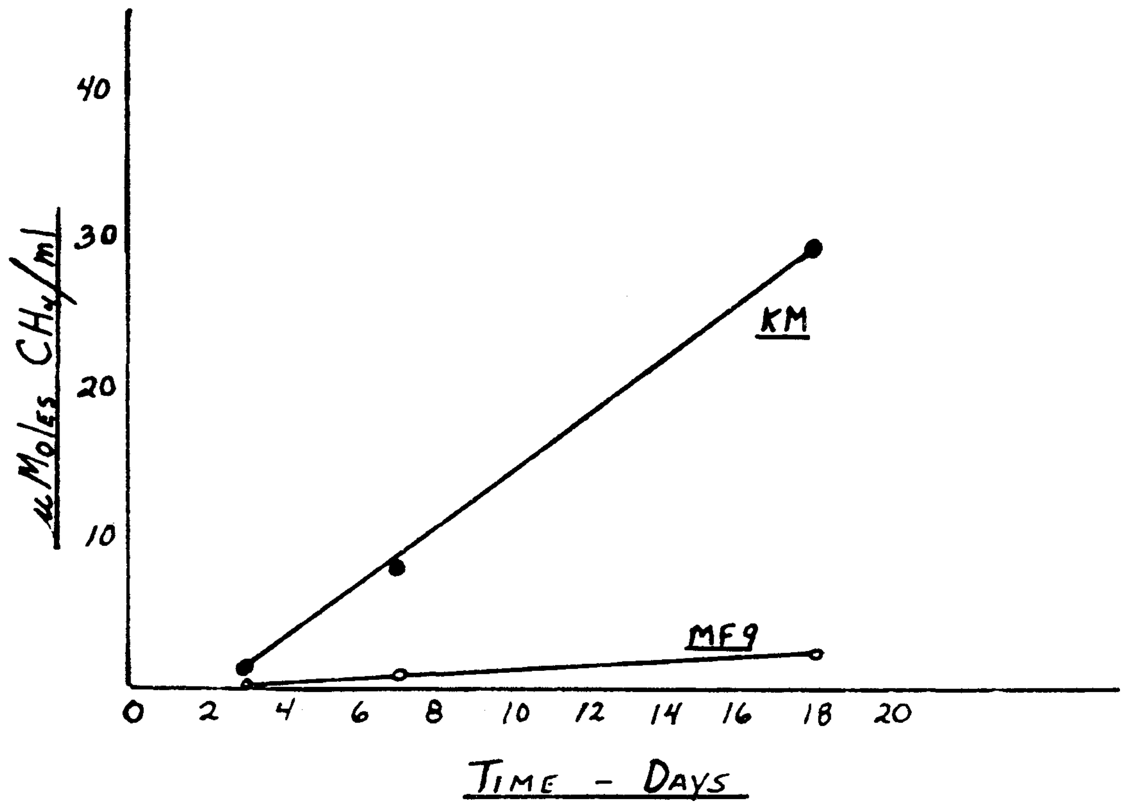


FIGURE 5. Methane Production by Two Calcium Butyrate Enrichments

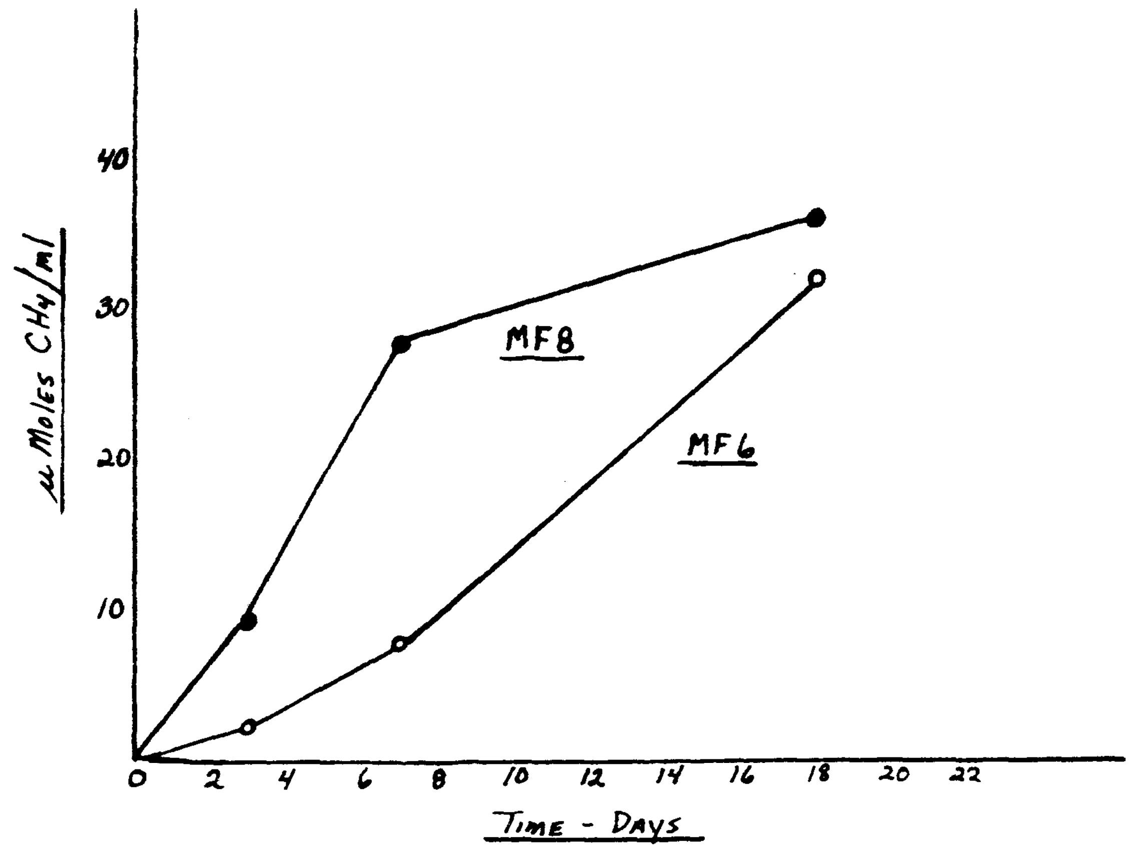


TABLE 9. EFFECT OF MEDIA SUPPLEMENTS ON METHANE PRODUCTION BY METHANOGENIC CALCIUM ACETATE ENRICHMENTS

Culture	Addition	μMoles CH_4/ml			
		Days: 3	6	10	17
MF-9	None	0.5	0.8	1.1	1.1
	Vitamins*	0.5	0.8	1.1	1.1
	0.2% Yeast Extract	1.1	2.3	3.7	13.4
KM	None	4.6	11.0	18.0	--
	0.2% Yeast Extract	5.1	11.4	16.5	--

* Vitamin mixture of Wolin *et al.*, 1963

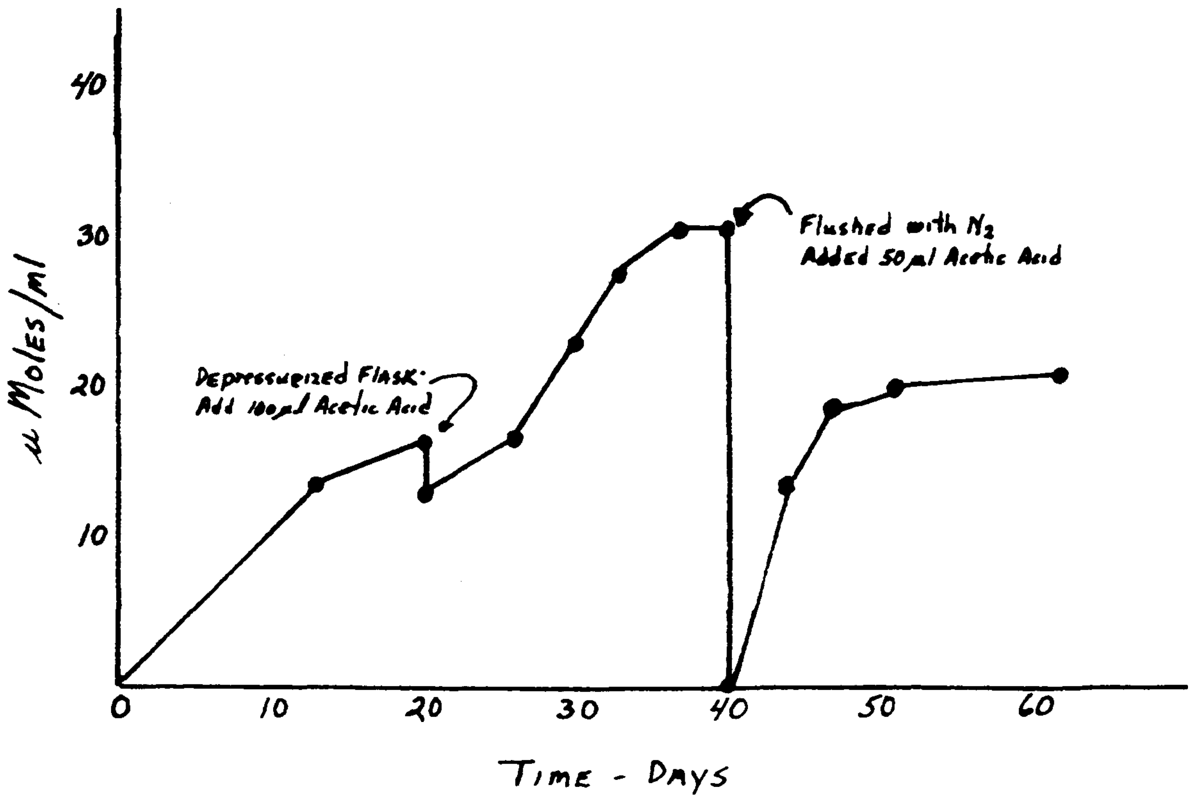


Figure 6. Effect of Addition of Acetate to Methanogenic Culture Derived From MF 8 Digester

D. COMPETITIVE CULTURES

Methanogen Isolation

Efforts are continuing to isolate pure cultures of methanogens. To date, several organisms have been isolated (some of which appear to be pure cultures) which grow well in isolation medium being employed, but which do not produce methane. These cultures include: a chain-forming coccus, a chain-forming bacilliary type, and a non-chaining spore former. Growth morphology in broth ranges from disperse to long stringy "ropes" and to "pellicles" covering the entire bottom of the culture bottle. As discussed in previous reports, the importance of these strains may lie in their competitive position with respect to methanogenic substrates. This aspect will be pursued at a later date.

IV. ALGIN UTILIZATION

An extensive study was made of the growth of a bacterial strain (39-1) which is one of the predominant alginate-utilizing strains isolated from alginate enrichments. This effort culminated in the presentation which follows, given at the 78th Annual Meeting of the American Society for Microbiology, Las Vegas, Nevada in May of this year.

ALGINATE UTILIZATION BY MARINE ANAEROBES

BY

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PRESENTED AT

78th ANNUAL MEETING

AMERICAN SOCIETY FOR MICROBIOLOGY

LAS VEGAS, NEVADA - 1978

ALGINATE UTILIZATION BY MARINE ANAEROBES

BY

JOHN R. FORRO, SENIOR MICROBIOLOGIST
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ALGIN IS A STRUCTURAL HETEROPOLYSACCHARIDE FOUND IN MANY MARINE ALGAE. IT HAS FOUND WIDE USE IN THE PHARMACEUTICAL AND FOOD INDUSTRIES AND, AS SUCH, THERE ARE SEVERAL COMMERCIAL OPERATIONS FOR HARVEST OF MARINE ALGAE AND SUBSEQUENT ALGIN RECOVERY.

STRUCTURALLY, ALGIN IS A MIXED POLYMER COMPOSED OF MANNURONIC AND GULURONIC ACID MONOMERS LINKED β 1 $\rightarrow$ 4. THESE MONOMERS ARE FOUND IN BOTH RANDOM ARRANGEMENTS AND IN BLOCK REGIONS RICH IN MANNURONIC RESIDUES OR GULURONIC RESIDUES.

OUR INTEREST IN ALGIN DERIVES FROM A GAS RESEARCH INSTITUTE SPONSORED PROGRAM INVESTIGATING THE CONVERSION OF THE GIANT BROWN KELP, <u>MACROCYSTIS PYRIFERA</u> TO METHANE GAS BY AN ANAEROBIC DIGESTION PROCESS. PART OF THIS PROGRAM HAS BEEN DIRECTED TOWARD A FUNDAMENTAL UNDERSTANDING OF THE MICROBIOLOGICAL AND BIOCHEMICAL ASPECTS OF THIS PROCESS AS IT APPLIES TO KELP DIGESTION BY MARINE-DERIVED ORGANISMS. IN PARTICULAR, ONE PORTION OF OUR STUDIES HAS DEALT SPECIFICALLY

WITH AN EXAMINATION OF THE STEPS IN THE UTILIZATION OF THE MAJOR COMPONENTS OF KELP, OF WHICH ALGIN IS THE MOST PROMINENT STRUCTURAL MATERIAL FOUND (I.E., 15-20% OF THE DRY WEIGHT ORGANIC MATTER).

PRELIMINARY EVALUATIONS OF EFFLUENTS FROM ANAEROBIC METHANE DIGESTORS RECEIVING RAW KELP FEED AND ESTABLISHED WITH MARINE-DERIVED INOCULA HAD INDICATED THAT A SIGNIFICANT PROPORTION OF ALGIN WAS NOT BEING DEGRADED IN THE PROCESS. SEVERAL QUESTIONS THUS AROSE AS TO WHAT THE MECHANISM WAS FOR ALGIN DEGRADATION UNDER ANAEROBIC CONDITIONS; I.E., WAS IT DIFFERENT FROM THAT PREVIOUSLY DESCRIBED FOR AEROBIC SYSTEMS, AND WHAT ORGANISMS WERE INVOLVED IN THIS MARINE-BASED ANAEROBIC PROCESS?

MARINE ENVIRONMENTAL SAMPLES WERE OBTAINED IN THE SAN DIEGO, CALIFORNIA, AREA WITH THE ASSISTANCE OF PERSONNEL AT THE NAVAL OCEAN SYSTEMS COMMAND (NOSC). SAMPLES INCLUDED SALT MARSH MUD, ROTTING KELP INCLUDING KELP FLIES, AND INTESTINAL CONTENTS OF SEA URCHINS AND ABALONE BEING FED KELP. RAW KELP WAS SUPPLIED BY NOSC AND WESTERN REGIONAL RESEARCH CENTER, ALBANY, CALIFORNIA.

DIGESTORS USING RAW KELP AS FEED, ALGIN UTILIZING ENRICHMENTS AND ALGINATE-TO-METHANE FOOD CHAINS WERE ESTABLISHED USING BOTH SINGLE AND MIXED SAMPLES AS INOCULA. ALL INCUBATIONS WERE CARRIED OUT AT EITHER ROOM TEMPERATURE (24°C) OR

37°C. ENRICHMENTS AND FOOD CHAINS WERE CONSTRUCTED USING A DEFINED MEDIA (WEIMER AND ZEIKUS, 1977) MODIFIED TO CONTAIN 3% NaCl AND WITH 0.5% (W/V) SODIUM ALGINATE AS SUBSTRATE. THE MEDIUM WAS DEPLOYED IN SEALED SERUM BOTTLES UNDER STRICT ANAEROBIC CONDITIONS USING N_2/CO_2 (80/20%) AS THE GAS PHASE.

ISOLATION OF ANAEROBIC ALGINATE DEGRADING MICROORGANISMS WAS ACCOMPLISHED USING ALGINATE ROLL TUBES AND ALGINATE PLATES (DILUTION AND STREAK) INCUBATED IN ANAEROBIC JARS (H_2/CO_2 ATMOSPHERE). COLONIES WERE PICKED TO ALGINATE SLANTS IN SERUM TOP TEST TUBES (BALCH AND WOLFE, 1976) AND LIQUID MEDIUM. USING THIS TECHNIQUE, SEVERAL PURE ISOLATES WERE OBTAINED AND SUBCULTURED FOR FURTHER STUDY.

A MICROSCOPIC EXAMINATION OF THE ISOLATES SHOWED ALL TO BE SIMILAR MORPHOLOGICALLY - LONG, THIN (0.3-0.4 x 10-15 μm), FLEXIBLE RODS, GRAM NEGATIVE, WITH COCCOID FORMS APPEARING IN OLDER CULTURES. OFTEN CELLS WERE SEEN WITH SPHERICAL PROTUBERANCES, RESEMBLING TERMINAL SPORES; BUT IT IS FELT THAT THESE ARE PROBABLY CELLS UNDERGOING LYSIS AND RELEASING CELL CONTENTS (I.E., PROTOPLASTS) RATHER THAN SPORES PER SE.

GROWTH ON AGAR PLATES WAS THIN AND SPREADING WITH WATER SOLUBLE PIGMENTS RANGING FROM YELLOW TO PINK BEING PRODUCED. THESE ISOLATES APPEARED TO BE RELATIVELY SENSITIVE TO OXYGEN AS NO GROWTH WAS NOTED UNDER AEROBIC CONDITIONS AND GROWTH

UNDER MICROAEROPHILIC CONDITIONS WAS DELAYED. MAXIMUM GROWTH WAS OBTAINED WITH STRICT ANAEROBIOSIS. SALT TOLERANCE TESTS SHOWED MOST STRAINS CAPABLE OF WITHSTANDING 7% SALT (AS NaCl).

THESE CHARACTERISTICS AND THE UNCERTAINTY OF THE EXISTENCE OF SPORES SEEMS TO PLACE THESE STRAINS IN THE GENUS CYTOPHAGA RATHER THAN IN GENUS SPOROCYTOPHAGA AS WAS ORIGINALLY INDICATED.

THE FREQUENCY OF OBSERVATION AND ISOLATION OF THESE STRAINS FROM KELP FERMENTATIONS AND ENRICHMENTS INDICATES THAT CYTOPHAGA STRAINS MAY BE THE PREDOMINANT MICROORGANISMS IN DIGESTION OF ALGIN IN KELP TO METHANE FERMENTATIONS. ONE STRAIN (39-1) WAS THUS CHOSEN FOR FURTHER STUDY OF ALGIN DEGRADATION UNDER ANAEROBIC CONDITIONS.

CULTURES WERE GROWN WITH AGITATION AT 32°C IN 125 ML CAPPED SERUM BOTTLES IN A DEFINED 0.5% ALGINATE MEDIUM UNDER A N_2/CO_2 (80/20%) ATMOSPHERE. SAMPLES WERE WITHDRAWN AT SPECIFIED INTERVALS FOR MEASUREMENT OF GROWTH, SUBSTRATE UTILIZATION, PRODUCT FORMATION AND ALGINASE ACTIVITY. PROCEDURES UTILIZED ARE LISTED IN TABLE I.

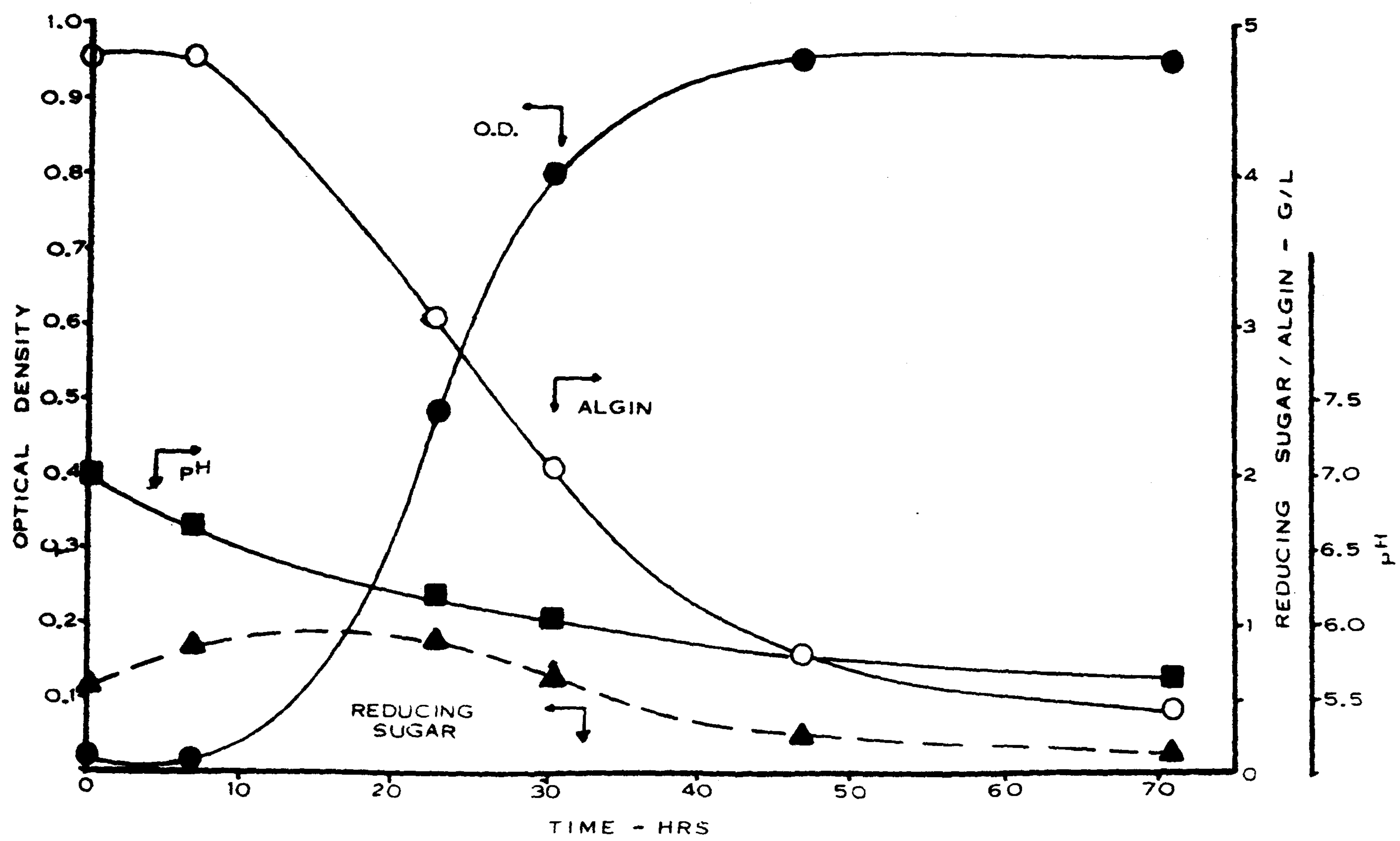
FIGURE I SHOWS THE GROWTH CURVE OBTAINED WITH THIS STRAIN. AFTER AN INITIAL LAG, GROWTH REACHES A MAXIMUM WITH A GENERATION TIME OF 2.5 HOURS. ALGIN UTILIZATION CLOSELY PARALLELS GROWTH AND REACHES A CALCULATED MAXIMUM RATE OF 0.2 $GM^{-1}HR^{-1}$.

TABLE I. ANALYSIS METHODS

PARAMETER	PROCEDURE	REFERENCE
GROWTH	OPTICAL DENSITY, 660 NM	--
ALGIN	ORCINOL REACTION	DISCHE, Z. J.B.C. 204:983 (1953) AS MODIFIED BY PREISS AND ASHWELL, J.B.C. 237:309 (1962)
VOLATILE ACIDS	GAS CHROMATOGRAPHY, 10% SP 1200/1% H_3PO_4 ON 80/100 CHROMOSORB W, AW	
NON-VOLATILE ACIDS	METHYL ESTERS ON 15% SP-1220/1% H_3PO_4	
LACTATE		BARKER AND SUMMERSON, J.B.C. 138:535 (1941)
ALGINASE	DINITROSALICYLIC ACID FOR REDUCING SUGARS	BERNFIELD, METHODS ENZYMOL. VOL 1, 149 (1955)
	ADSORPTION AT 230 NM	PREISS AND ASHWELL, J.B.C. 237:309 (1962)
ALGINASE PRODUCTS	TLC (EASTMAN 6060 SILICA: PYRIDINE : ETHYL ACETATE : ACETIC ACID : H_2O - 5:5:1:3 - SILVER NITRATE DETECTION)	
	PAPER CHROMATOGRAPHY - SAME SOLVENT AND DETECTION REAGENT.	

FIGURE I

GROWTH OF 39-1 ON ALGINATE



APPROXIMATELY 80% OF THE ALGIN IS CONSUMED WHEN GROWTH CEASES, WITH AN ADDITIONAL 10-12% BEING FURTHER CONSUMED.

REDUCING SUGARS, AFTER AN INITIAL INCREASE, GRADUALLY WERE CONSUMED. AS WILL BE SHOWN LATER, THE REDUCING COMPOUNDS ARE PROBABLY NOT URONIC ACIDS, BUT RATHER UNSATURATED CLEVAGE PRODUCTS OF ALGIN. THE pH OF THE MEDIUM DROPPED RAPIDLY FROM AN INITIAL VALUE OF pH 7.0 TO A FINAL pH of 5.6. THIS DROP IN pH IS COINCIDENT WITH PRODUCTION OF THE VOLATILE FATTY ACIDS ACETATE AND PROPIONATE AS SHOWN IN FIGURE II. HIGHER MOLECULAR WEIGHT ACIDS OR ETHANOL WERE NOT DETECTED AND ONLY SMALL AMOUNTS OF LACTATE (<10 MG/L) AND SUCCINATE (80 MG/L) WERE FOUND. CELL-FREE ALGINASE ACTIVITY WAS NOTED TO INCREASE THROUGHOUT THE COURSE OF THE FERMENTATION AND CONTINUED TO INCREASE AFTER GROWTH PER SE CEASED. ALTHOUGH THERE WAS NO MEASURABLE DROP IN OPTICAL DENSITY IN THE LATER STAGES OF GROWTH PERIOD, CONSIDERABLE LYSIS WAS OBSERVED MICROSCOPICALLY AND PROBABLY ACCOUNTS FOR THE INCREASE OF ALGINASE ACTIVITY (FIGURE III).

A BRIEF SURVEY OF ALGINASE ACTIVITY WAS MADE IN ORDER TO DEFINE SOME OF ITS IMPORTANT PARAMETERS. A pH ACTIVITY PROFILE (FIGURE IV) SHOWED THIS ENZYME TO HAVE A RATHER BROAD ACTIVITY RANGE, WITH A MAXIMUM AROUND pH 8.0. THUS, THIS ENZYME SYSTEM APPEARS TO HAVE pH ACTIVITY REQUIREMENT

FIGURE II

VOLATILE ACID PRODUCTION BY 39-1 FROM ALGINATE

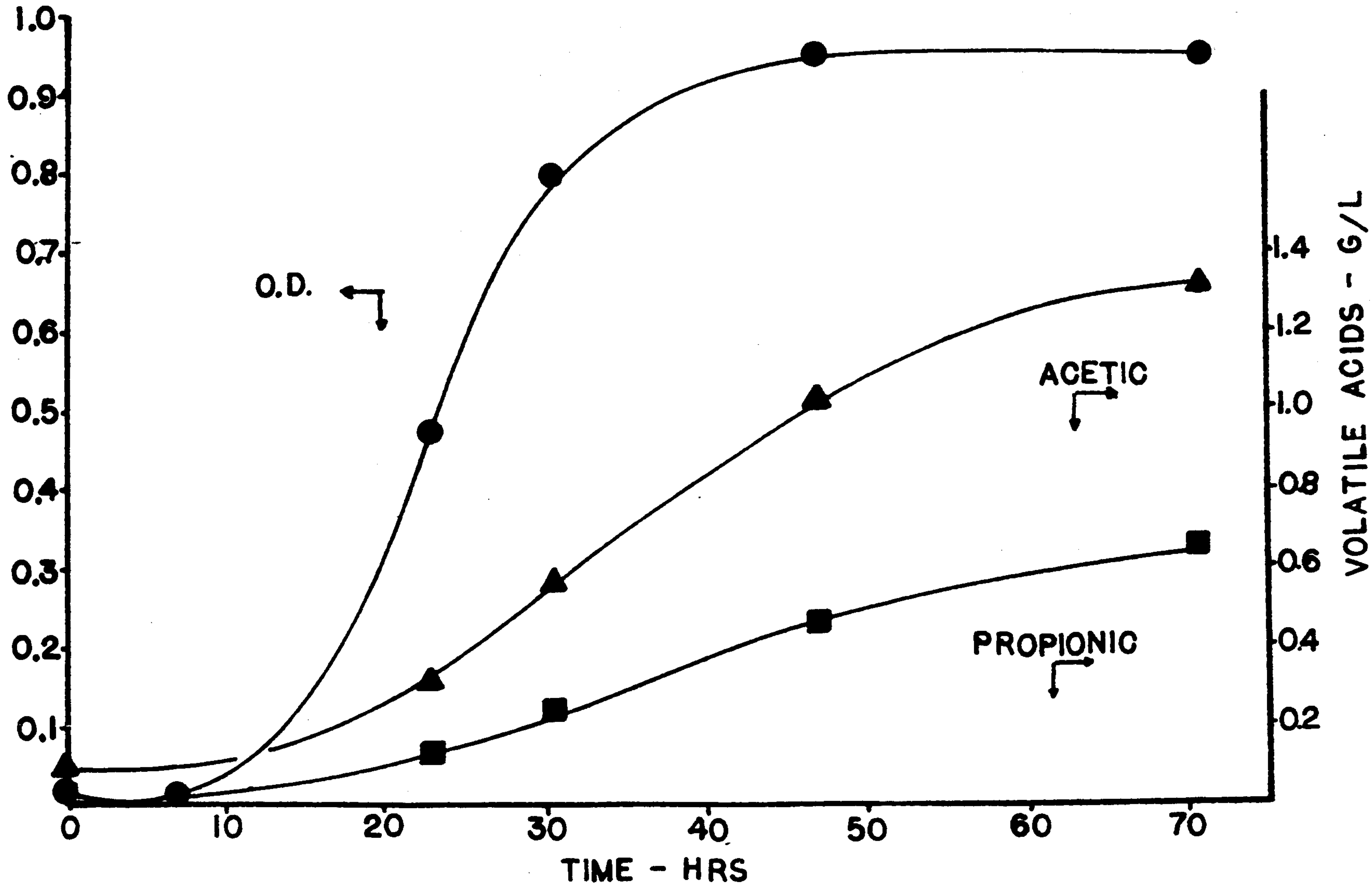
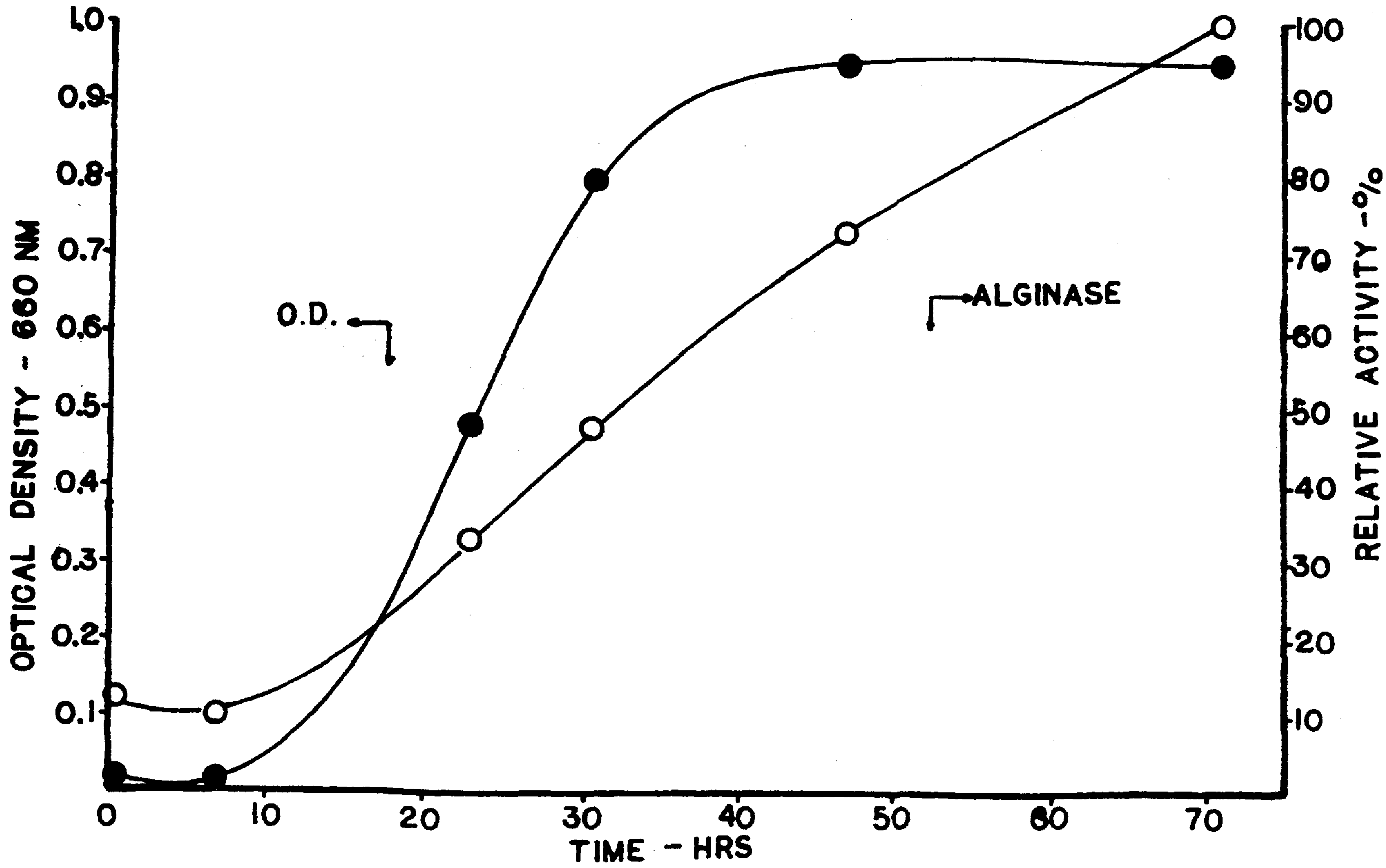


FIGURE III

39 - I

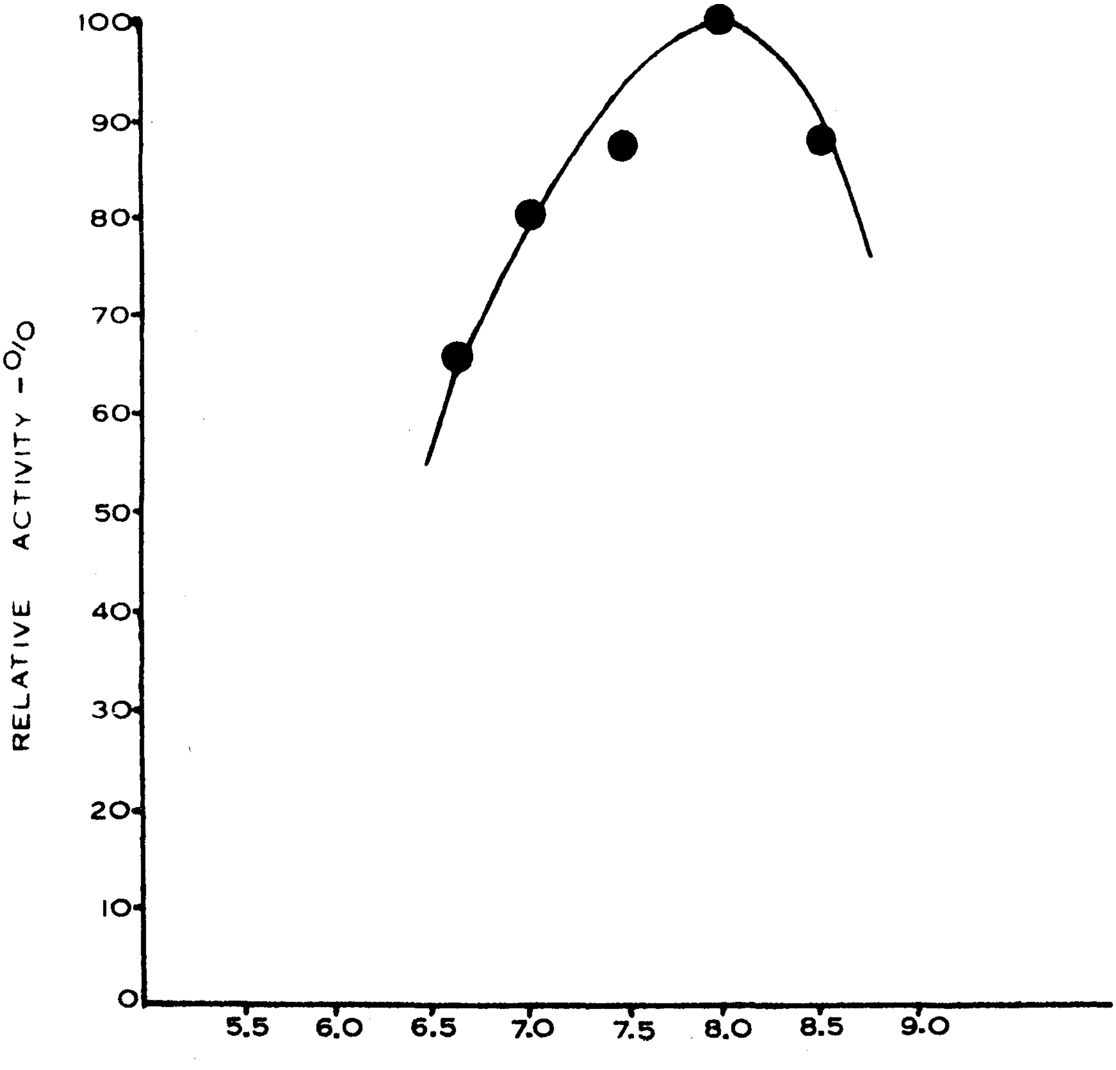
ALGINASE ACTIVITY AND GROWTH



35
157

FIGURE IV

pH ACTIVITY PROFILE OF 39-1 ALGINASE



SIMILAR TO OTHER ALGINASE SYSTEMS THAT HAVE BEEN DESCRIBED FOR A PSEUDOMONAS (KASHIWABARA ET AL., 1969) AND ALGINOVIBRIO (STEVENS AND LEVIN, 1977).

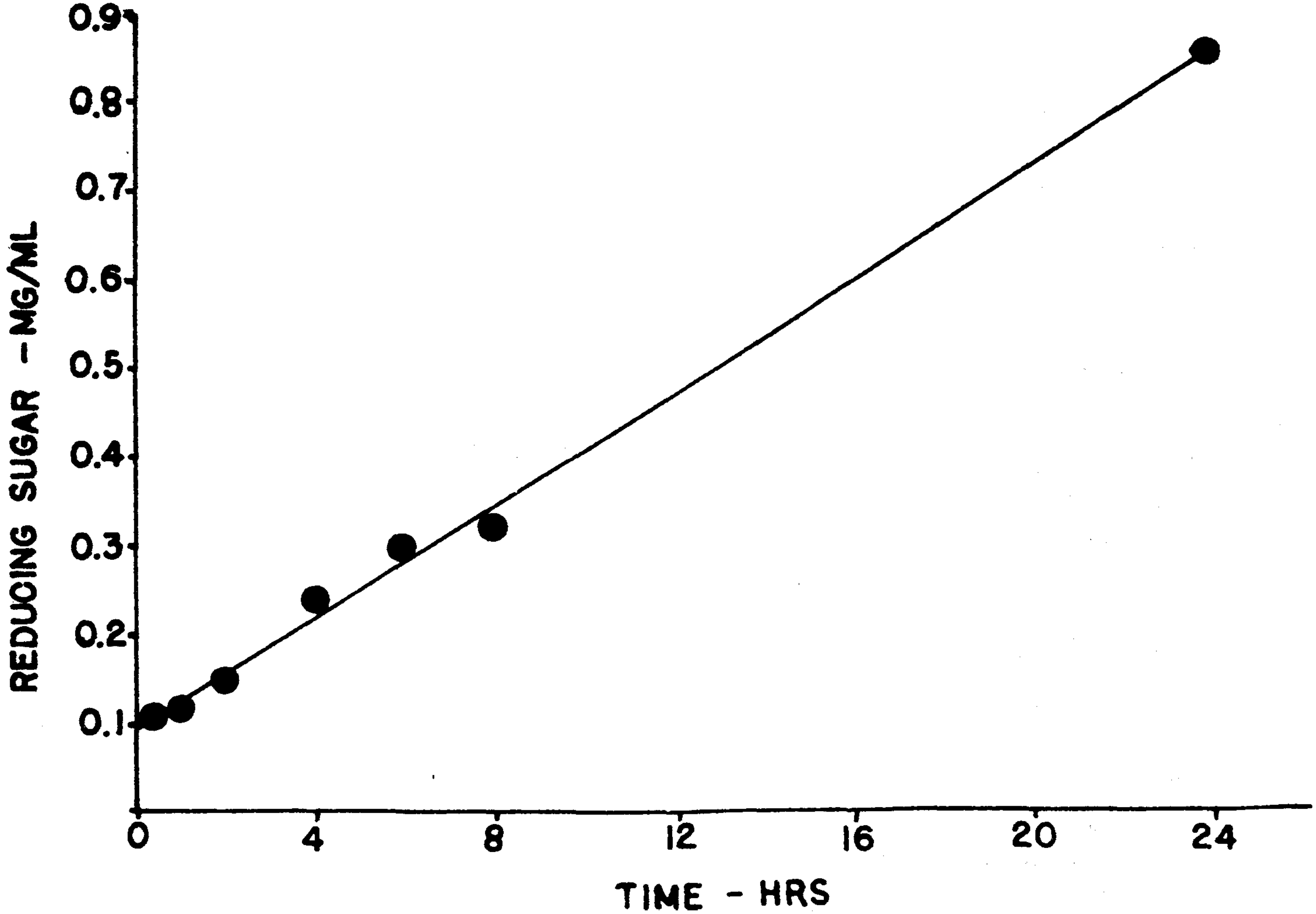
THE ALGINASE ENZYME SYSTEM APPEARS TO HAVE EXCELLENT STABILITY AS EVIDENCED BY DATA PRESENTED IN FIGURE V, WHICH SHOWS A VERY LINEAR REACTION FOR A 24-HOUR PERIOD (REACTION RUN AT 37^{o}C).

PREISS AND ASHWELL (1962) SHOWED THAT AN ALGINASE ENZYME COMPLEX FROM A PSEUDOMONAD DEGRADED ALGIN TO 2 KETO-3-DEOXY GLUCONATE VIA AN UNSATURATED OLIGOSACCHARIDE INTERMEDIATE WHICH SHOWED AN ABSORPTION MAXIMUM AT 230 NM. ON THE BASIS OF THIS AND OTHER DATA, THEY POSTULATED THE REACTION MECHANISM SHOWN IN FIGURE VI. AN EXAMINATION OF THE REACTION PRODUCTS OF OUR CYTOPHAGA ALGINASE ENZYME SYSTEM ALSO SHOWED THE RAPID APPEARANCE OF COMPOUNDS ABSORBING IN THE 230 NM REGION INDICATING A MECHANISM SIMILAR TO THAT FOUND IN PSEUDOMONADS. IN ORDER TO PRECLUDE THE POSSIBILITY THAT THESE CELL-FREE BROTHS DID NOT ALSO CONTAIN HYDROLYTIC ACTIVITY RESULTING IN RELEASE OF URONIC ACID MONOMERS OR DIMERS IN ANALOGY TO CELLULOLYTIC ENZYME SYSTEMS, LONG-TERM (24 HR) REACTION MIXTURES WERE ANALYZED BY TLC AND PAPER CHROMATOGRAPHIC PROCEDURES. STANDARD URONATES WERE PREPARED BY ACID HYDROLYSIS OF ALGIN (HAUG AND LARSEN, 1962) AND WERE SEPARATED BY GRADIENT ELUTION CHROMATOGRAPHY ON BIORAD AG-1-X8 (ACETATE FORM). THE R_f VALUES OBTAINED IN THIS EXPERIMENT ARE SHOWN IN TABLE II.

FIGURE V.

PRODUCTION OF REDUCING SUGAR FROM ALGINATE

BY 39-1 ALGINASE



ALGINIC ACID

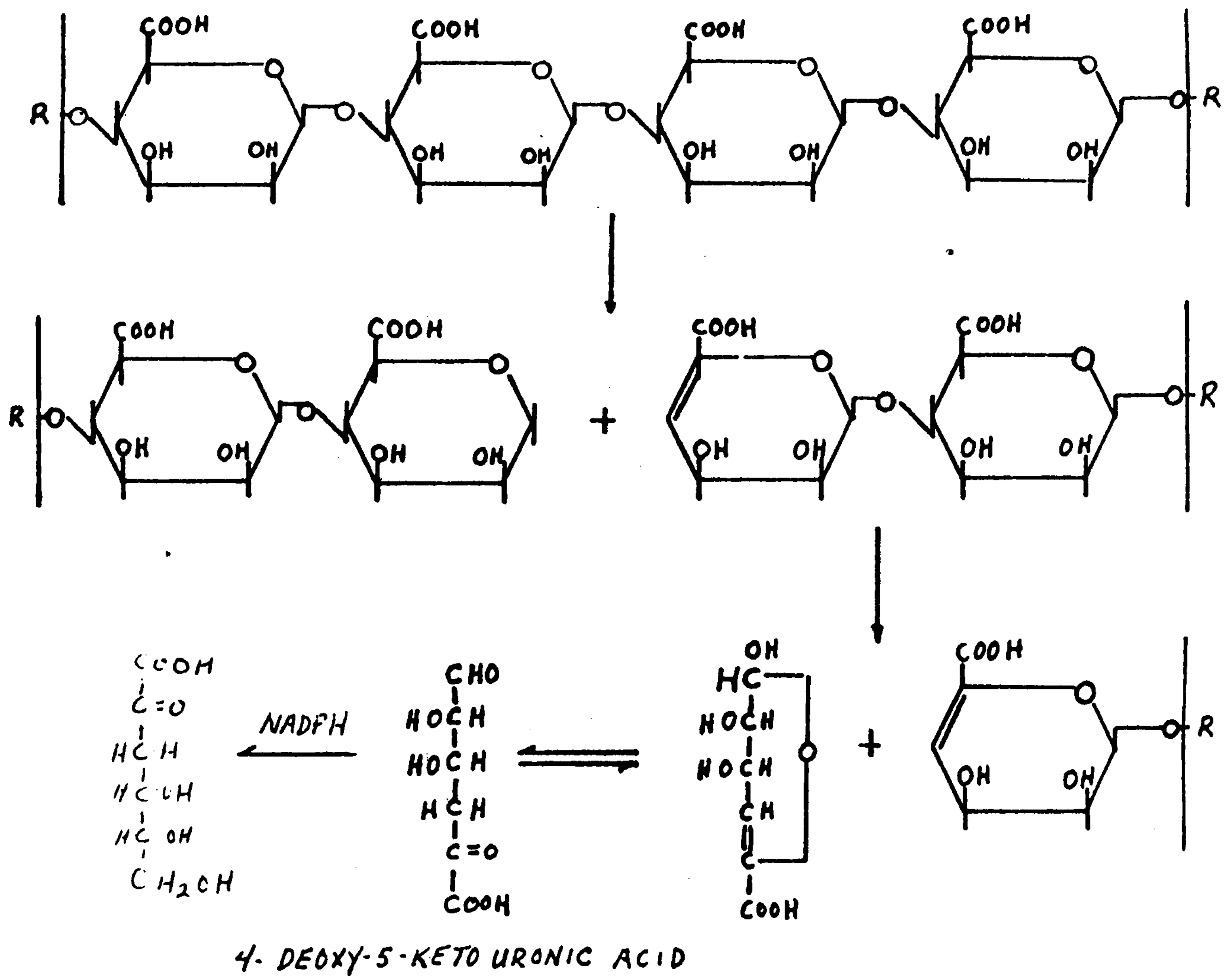


FIGURE VI

Enzymatic Degradation of Alginic Acid

TABLE II. TLC AND PAPER CHROMATOGRAPHY OF ALGINASE REACTION PRODUCTS

	SILICA GEL	PAPER (WHATMAN #1)
MANNURONIC	0.81	0.35
GULURONIC	0.81	0.36
ENZYMATIC HYDROLYSATE	0.68	0.46

ALTHOUGH THE IDENTITY OF THE SPOTS APPEARING IN THE ENZYMATIC HYDROLYSATES HAVE NOT BEEN IDENTIFIED, THESE DATA CLEARLY SHOW THAT MANNURONIC AND GULURONIC ACIDS ARE NOT BEING PRODUCED AT DETECTABLE LEVELS BY THIS ENZYME SYSTEM AND SUGGEST THAT ALGIN IS BEING DEGRADED SOLELY BY A LYASE REACTION AS PREVIOUSLY DESCRIBED.

IN SUMMATION, WE HAVE EXAMINED THE APPARENTLY PREDOMINANT MARINE SPECIE RESPONSIBLE FOR ALGIN DEGRADATION IN A SERIES OF KELP-TO-METHANE DIGESTIONS AND ALGIN ENRICHMENTS AND HAVE FOUND THEM TO BE MEMBERS OF THE GENUS CYTOPHAGA. ALL ISOLATES WERE MICROAEROPHILIC, BUT GREW BEST UNDER ANAEROBIC CONDITIONS. DATA IS PRESENTED THAT INDICATES THAT THESE STRAINS DEGRADE ALGIN VIA PATHWAYS PREVIOUSLY DESCRIBED FOR PSEUDOMONADS, THAT IS, VIA A LYASE TYPE REACTION TO YIELD 2-KETO-3 DEOXY GLUCONATE AND TO PRODUCE MAINLY ACETATE AND PROPINATE AS METABOLIC END PRODUCTS.

THE WORK REPORTED IN THIS PAPER WAS SUPPORTED BY THE GAS RESEARCH INSTITUTE, CHICAGO, ILL. THROUGH THE MARINE BIOMASS PROGRAM.

V. MANNITOL UTILIZATION

A. SHAKE CULTURE SCREENING

Three mannitol utilizing cultures were grown in serum bottles on 0.5% mannitol medium at 31°C on a reciprocating shaker. The purpose of this experiment was to establish some boundary parameters prior to determining which large-scale culture to use under defined conditions at the 5-liter level. The data for culture A14B are presented in Table 10. From these data, it is evident that A14B produces large quantities of acid which probably, in turn, inhibit its continued growth in poorly buffered systems. It is apparent, therefore, that pH control is essential for growing significant populations of this organism.

B. MANNITOL FERMENTATIONS

Five-liter fermentations were run with culture A14B, using 0.5% mannitol as the carbon source in the basal medium of Weimer and Ziekus (1977). The initial atmosphere was 20% CO_2, 80% N_2 and the pH was controlled at pH 6.7, by automatic addition of 5% NaOH. Growth (as O.D. at 650 nm), residual mannitol (by HPLC), alcohols and volatile fatty acids (by GC), and NaOH consumption were determined at periodic intervals. Typical data are presented in Tables 11 and 12, and in Figure 7.

Acetate was the only VFA produced in significant quantities, and its production accounts for only 1/3 of the NaOH consumed and for only up to 21% of the utilized mannitol. Since it is unlikely that CO_2 production accounts for all the remaining acidity, other acids are probably being produced. (At the time these experiments were conducted, procedures for analysis of non-volatile acids were not a part of this laboratory's capabilities, but since have been added - see Methods Development.) From the literature, however, the most likely candidate acids are formate and succinate. Lactic acid levels in the first fermentation were very low (<0.4 gm/l).

However, Ethanol was produced in relatively large quantities in these fermentations. About 40 to 45% of the utilized mannitol carbon appeared as ethanol. From these data, it is evident that a significant fraction (up

TABLE 10

GROWTH OF MANNITOL CULTURE A14B ON SHAKER[1]

Sample Number	Experimental Time (hours)	OD_{650}	pH	1% NaOH Added (ml)	Acetic[2] Acid (ppm)	Mannitol Utilized (%)
1	0	0.053	7.1	--	--	--
2	2	0.092	7.1	--	--	--
3	4	0.092	--	--	--	--
4	6	0.185	6.85	--	--	--
5	23.5	0.438	5.4	--	385	--
6	25.5	0.433	5.3	1	--	--
7	27.5	0.405	5.8	2	--	--
8	30.5	0.434	6.3	--	--	62
9	95.5	--	--	--	585	100

(1) 4% inoculum of 18-hour culture.
60 ml total volume. Initial atmosphere 20% CO_2 in N_2.
Temperature 31°C. Incubated at 130 strokes/min on reciprocating air bath shaker.

(2) Acetic acid was the only VFA present in significant amounts.

TABLE 11

SUMMARY OF MANNITOL FERMENTATION #2 (1)

Sample Number	Experimental Time (hrs)	OD_{650}	Mannitol Remaining (ppm)	Mannitol Utilized (%)	Ethanol (ppm)	Acetic Acid (2) (ppm)	NaOH Used Total (gm)	NaOH Used Change (gm)
1	0	0.108	5075	0	29	94	0	0
2	2	0.155	5120	0	74	133	0.5	0.5
3	4	0.250	4505	11.2	166	123	2.0	1.5
4	6	0.360	3460	31.8	338	220	4.0	2.0
5	8	0.554	2610	48.6	603	550	7.0	3.0
6	10	0.622	1240	75.6	989	638	9.0	2.0
7	14	0.720	0	100.0	1582	1160	13.2	4.2
8	24	0.678	0	100.0	1453	1008	13.2	0

(1) 4% inoculum of 22-hour culture A14B. 5 liters total volume. Initial atmosphere 20% CO_2 in N_2. Temperature 33°C. pH controlled at 6.7.

(2) Acetic acid was the only VFA present in significant amounts.

TABLE 12

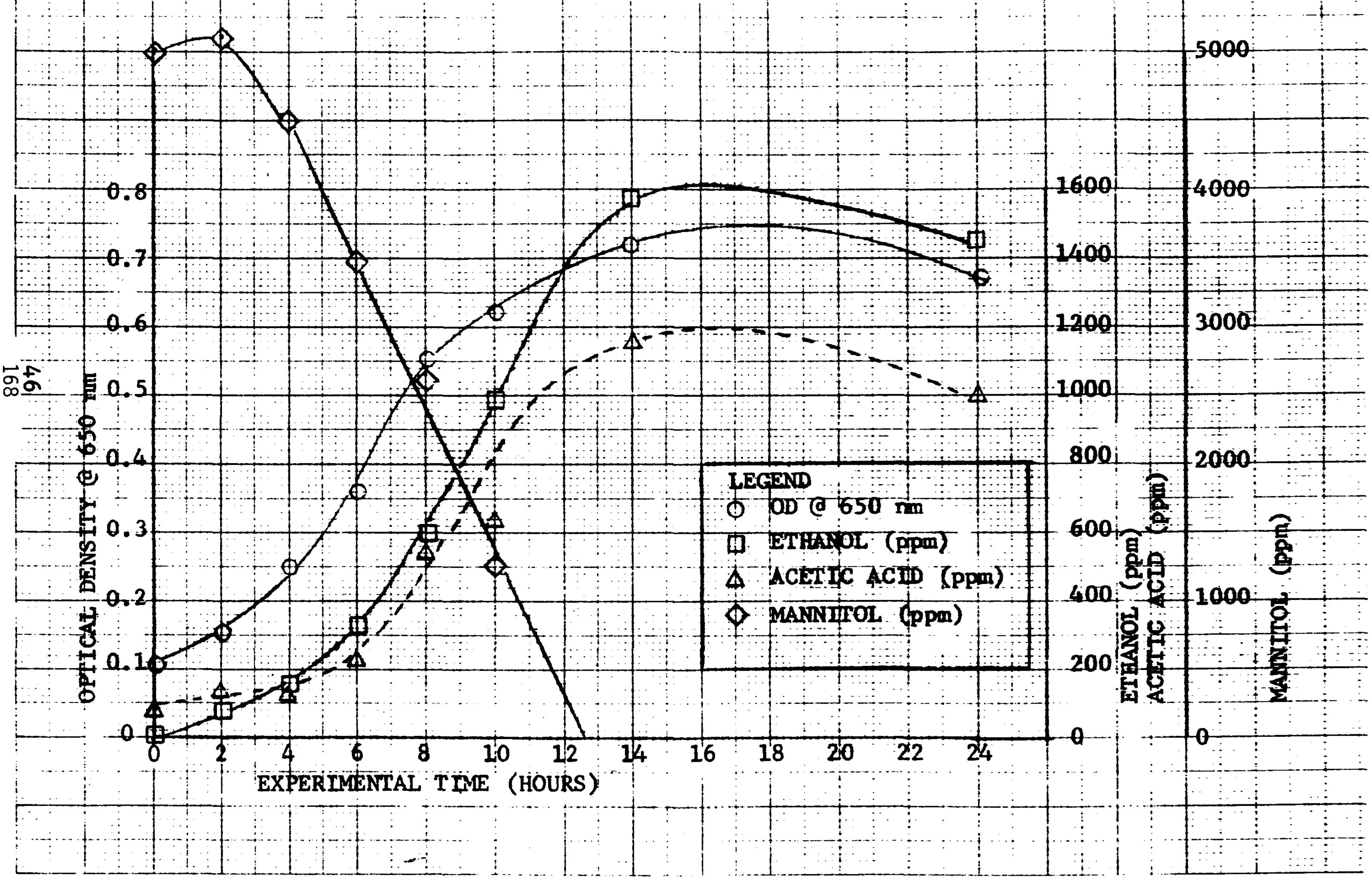
CARBON BALANCE ON MANNITOL FERMENTATION #2[1]

Sample No.	Experimental Time (hrs)	Mannitol Carbon Utilized (ppm)	Carbon Produced: Ethanol (ppm	Carbon Produced: Acetic Acid (ppm)	Percent Utilized Mannitol Carbon in Ethanol plus Acetic Acid[2]
1	0	0	0	0	0
2	2	0	23	16	0
3	4	225	71	12	36.9
4	6	638	161	50	33.1
5	8	974	298	182	49.3
6	10	1515	499	218	47.3
7	14	2005	773	426	59.8
8	24	2005	740	363	55.0

(1) 4% inoculum of 22-hour culture A14B. 5 liters total volume. Initial atmosphere 20% CO_2 in N_2. Temperature 33°C. pH controlled at 6.7.

(2) Assuming no CO_2 fixation.

Figure 7. GROWTH OF A14B ON MANNITOL
SECOND FERMENTATION RUN



to 60%) of the utilized mannitol carbon appears in ethanol and acetic acid (assuming no CO_2 fixation).

In these fermentations, the mannitol was completely utilized in about 14 hours. This implies residual mannitol should be at very low levels in a continuous kelp fermentation having a 6-day retention time. The ethanol produced by this pure culture would probably be converted to acetic acid in the presence of hydrogen-utilizing bacteria.

VI. CELLULOSE DEGRADATION STUDIES

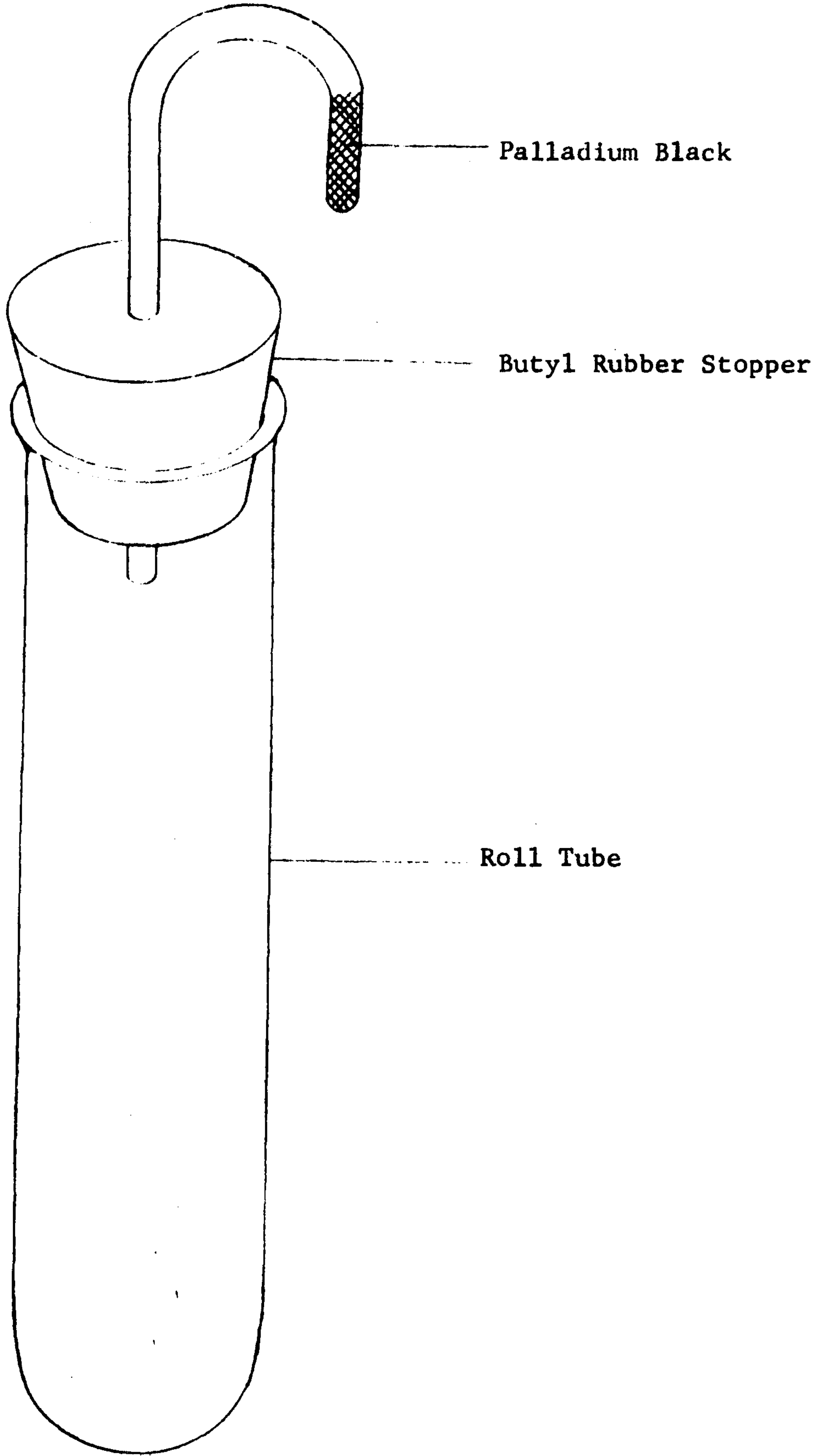
As described in previous reports, effort is being devoted to the study of cellulose degradation with marine derived anaerobic cultures, as cellulose hydrolysis appears to be a major rate limiting step in the conversion of kelp to methane.

Several enrichment cultures capable of degrading filter paper strips have been established and are being maintained. These enrichments caused a complete loss of filter paper (Whatman) integrity within 10 days at 35°C. Attempts to isolate the bacterial strains effecting the primary cellulose hydrolysis steps have been tried utilizing conventional roll tube techniques (Hungate) containing ball-milled cellulose media. These have not proved successful. Although numerous colony types develop in these tubes, none have been found to be capable of hydrolyzing cellulose when cultured individually. In addition, at no time have clearing zones indicative of extracellular cellulase activity been noted in these media.

Several of these enrichment cultures showed no evidence of cellulolytic activity in 30 days when the atmosphere was changed from N_2/CO_2 (80:20) to H_2CO_2 (80:20) indicating potential hydrogen toxicity or repression as has been noted in other culture systems (Weimer and Ziekus, 1977; Chung, K-T, 1976). Enrichments were therefore established in which palladium black was utilized as a scavenger of hydrogen, thereby reducing any repressive effects of this gas on the subsequent utilization of cellulose by monocultures of cellulolytic organisms. The configuration of these enrichment roll tubes is shown in Figure 8. This technique did not, however, yield any cellulolytic strains.

At this point, the cellulose substrate was changed from filter paper to Walseth Cellulose (a phosphoric acid swollen, highly amorphous cellulose). With this substrate, complete degradation

FIGURE 8. MODIFIED ROLL TUBE FOR ISOLATION OF CELLULOSE DEGRADING MARINE ANAEROBES



occurs within 48 hours, with the organisms forming a very firm mat. Microscopic examination of these enrichments indicates a predominance of *Cytophaga*-like organisms. Roll tubes of these enrichments with this amorphous cellulose, however, have not yielded any surface or subsurface colonies. As it is possible that these organisms may require an inducer or an initial period of growth for cellulolytic activity, roll tubes were established as above, but supplemented with low levels of cellobiose (0.05%) and/or with filter sterilized filtrate from an actively growing cellulose enrichment. Using this approach, definite colonies have been observed in roll tubes and are in the process of being evaluated for cellulolytic activity.

VII. SALT TOLERANCE STUDIES

A. SALT TOLERANCE OF MANNITOL CULTURES

The salt (NaCl) tolerance of three mannitol isolates was examined in mannitol broth containing 3 to 8% NaCl. Cultures A14B and A28 grew well in 7% salt, but evidenced no growth at 8%. Culture A10I1 grew well in 8% NaCl. In gross cultural appearance, A10I1 and A14B demonstrated disperse growth, but A28 exhibited considerable "ropiness" at concentrations above 4%. This "ropiness" became more pronounced as the salt concentration increased. The only VFA produced was acetic acid. The acetate levels at 7% NaCl appeared to be higher than at 3% (Table 13), but were in no case as high as in the pH controlled mannitol fermentations. VFA's were only determined on the 3% and 7% salt samples.

TABLE 13

ACETIC ACID PRODUCTION DURING THE
SALT TOLERANCE EXPERIMENT ON MANNITOL UTILIZING CULTURES

Culture	NaCl (%)	Acetic Acid (ppm)
A10I1	3	85
	7	151
A14B	3	106
	7	165
A28	3	46
	7	112

B. SALT TOLERANCE OF ALGINATE UTILIZERS

The alginate utilizing bacterial strain 39-1 was examined for its ability to grow in an alginate broth containing salt levels ranging from 3 to 7% (as NaCl). No apparent difference, either macroscopically or microscopically, was noted between cultures at any concentration, thus indicating that these bacteria would be able to function in a digester operating at maximum solids loading.

VIII. METHODS DEVELOPMENT

A. ANALYSIS OF NON-VOLATILE ACIDS

Several procedures for quantitating the non-volatile acids produced by kelp fermentations, and by selected strains utilizing kelp constituents, were compared. The most reproducible technique was selected as the method to be used in all subsequent work. The methyl ester derivitization procedure is that of the VPI Anaerobe Laboratory (Holdeman, L. V. and W. E. C. Moore (Eds.). 1975. The Anaerobe Laboratory Manual. VPI, Blacksburg, Va.). The column used was 15% SP-1220/1% H_3PO_4 on 100/120 Chromosorb W AW, 6 feet by 1/4" O.D., 4 mm I.D. glass. Samples were run on a Varian 3700 gas chromatograph utilizing a thermal conductivity detector at 170°C. Injector temperature was 160°C and the column was 115°C. Figure 9 shows a typical chromatogram obtained using standard acids.

B. MANNITOL ASSAY

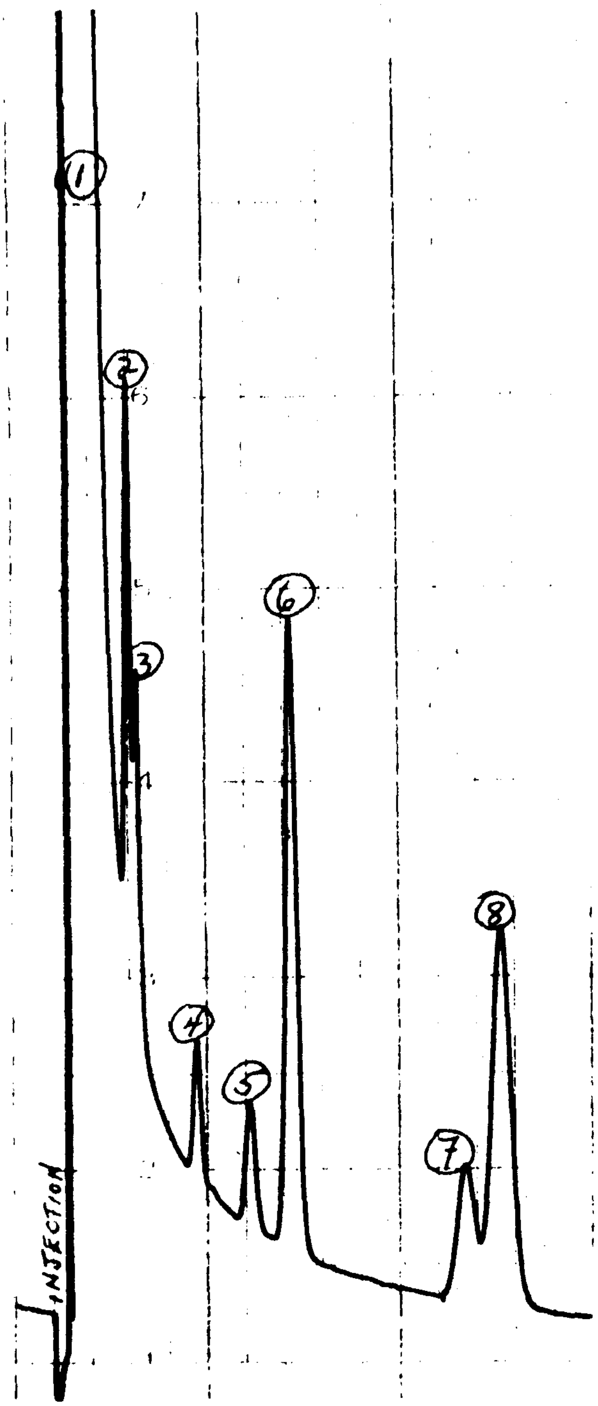
The HPLC mannitol assay previously described was modified as follows to further separate mannitol from the large accompanying salt peak.

Instrument: Waters Associates model 201 Liquid Chromatograph with model 6000A Solvent Delivery System and model U6K Injector

Column: Waters Associates μ-Carbohydrate

Detector: Waters Associates model R-401 differential refractometer

FIGURE 9. GAS CHROMATOGRAM OF METHYL DERIVATIVES OF NON-VOLATILE ACIDS



PEAK IDENTIFICATION

1. SOLVENT
2. PYRUVIC ACID
3. LACTIC ACID
4. OXALIC ACID
5. OXALACETIC ACID
6. METHYL MALONIC AND MALONIC ACIDS
7. FUMARIC ACID
8. SUCCINIC ACID

Data Analysis: Varian Associates model CDS 111 Chromatographic Data System

Solvent: 85% Acetonitrile : 15% water

Flow Rate: 1.8 ml/min

Pressure: 1000 PSI

Pressure Limit: 2000 PSI

Refractive Index Polarity: Negative

C. VOLATILE ALCOHOL ANALYSIS

A quantitative assay for low molecular weight alcohols occurring in fermentor broths has been established.

The equipment consists of a Varian model 1800 GC fitted with a 6' x 1/8" ID stainless steel column packed with Porapak Q (Applied Science Labs, State College, Pa.)

Assay Conditions are:

Column temperature	200°C
Gas flow	30 ml/min N_2
Detector	HFID
Range	10^{-11} mA
Temperature	250°C
Injector temperature	240°C

Peak areas are integrated and converted to concentration with a Varian CDS 111 chromatographic data system.

IX. FEED-CONTROLLED DIGESTERS

In order to develop large populations of marine methanogens effecting the conversion of acetete to methane, it was considered necessary to utilize fermenters in which the acetate is fed at a rate which is established by the microbial concentration. A similar technique has proved successful in cultivation of formate utilizing methanogens where it was shown that substrate concentrations necessary to develop large cell populations were, in turn, inhibitory to small inocula. Thus, as the population of cells increases, more substrate must be provided.

The fermenter that was designed and shown schematically in Figure 10 consists of a continuously stirred temperature controlled digester vessel with provisions for gas collection, and overflow fluid collection for continuous or semi-continuous operation. Substrate feed is controlled via a pH probe which is connected to a pH controller. As pH changes due to substrate consumption, the pH controller activates a peristaltic pump which, in turn, feeds substrate at a predetermined rate until the set point pH is reestablished.

Preliminary experiments utilizing this fermenter concept were in progress when it was found that ingredients (i.e., tryptone) in medium being employed were a source of additional fatty acids which caused fluctuations in pH and monitoring of substrate consumption (i.e., acetate) difficult (see discussion in Feeding Trail Experiment).

Further work with this system has thus been delayed until media formulations have been definitized.

X. LARGE SCALE ANAEROBIC DIGESTER

In order to meet commitments for scale-up of bench scale laboratory digesters, effort was placed on the design, component procurement and construction of two 70-liter (60-liter working volume) digesters. The design, detailed in Figures 11-A to -E, took into consideration requirements for monitoring of performance parameters and potential for introduction of increased size kelp feed. Materials selected for construction were chosen for compatibility with microbial systems, strongly reducing environments and the high salinity of the reaction mixture. A list of major components and ancillary equipment is provided in Table 14.

FIGURE 10. SCHEMATIC OF pH CONTROLLED DIGESTER

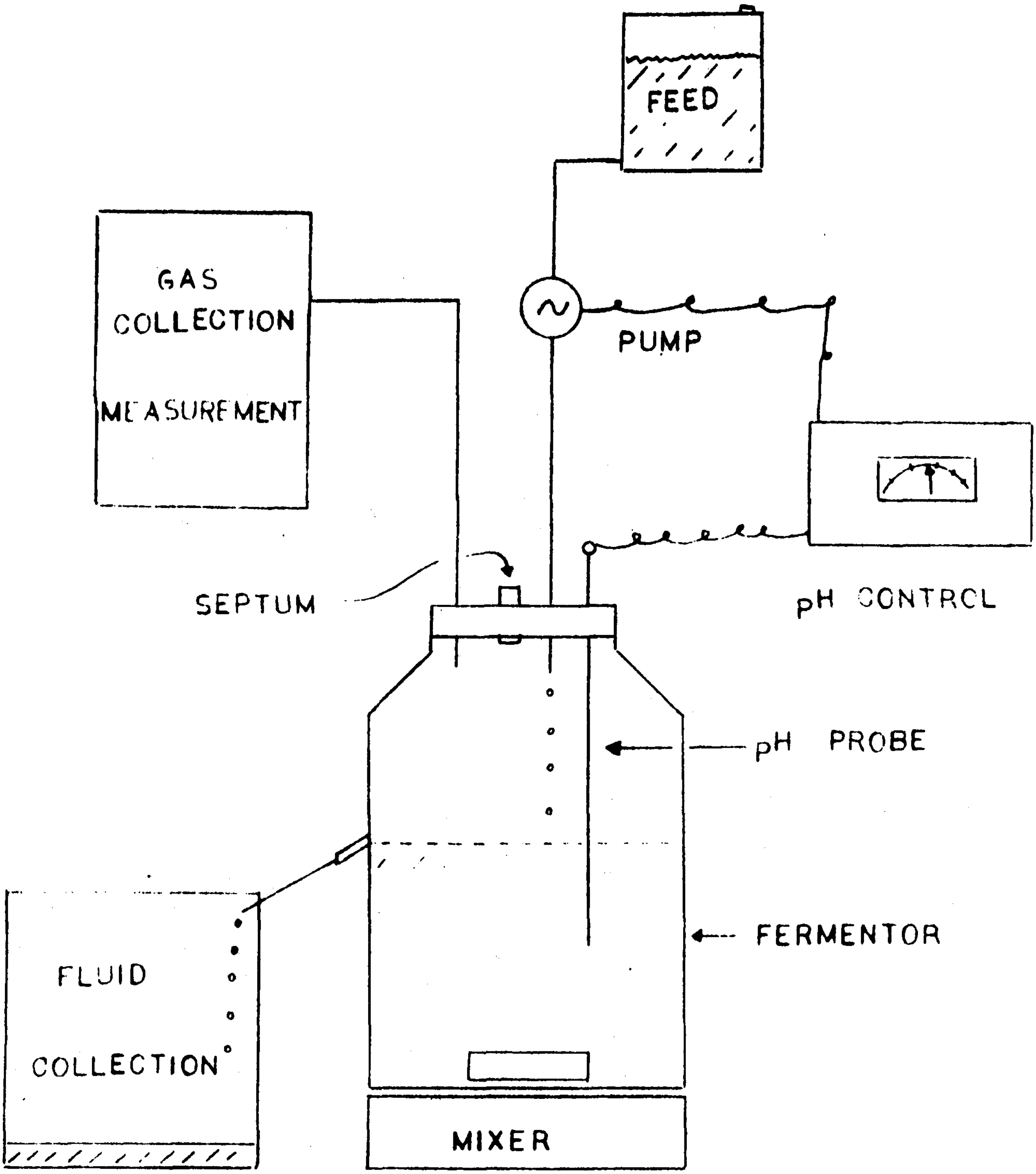


FIGURE 11-A. 70-LITER DIGESTER (ASSEMBLY)

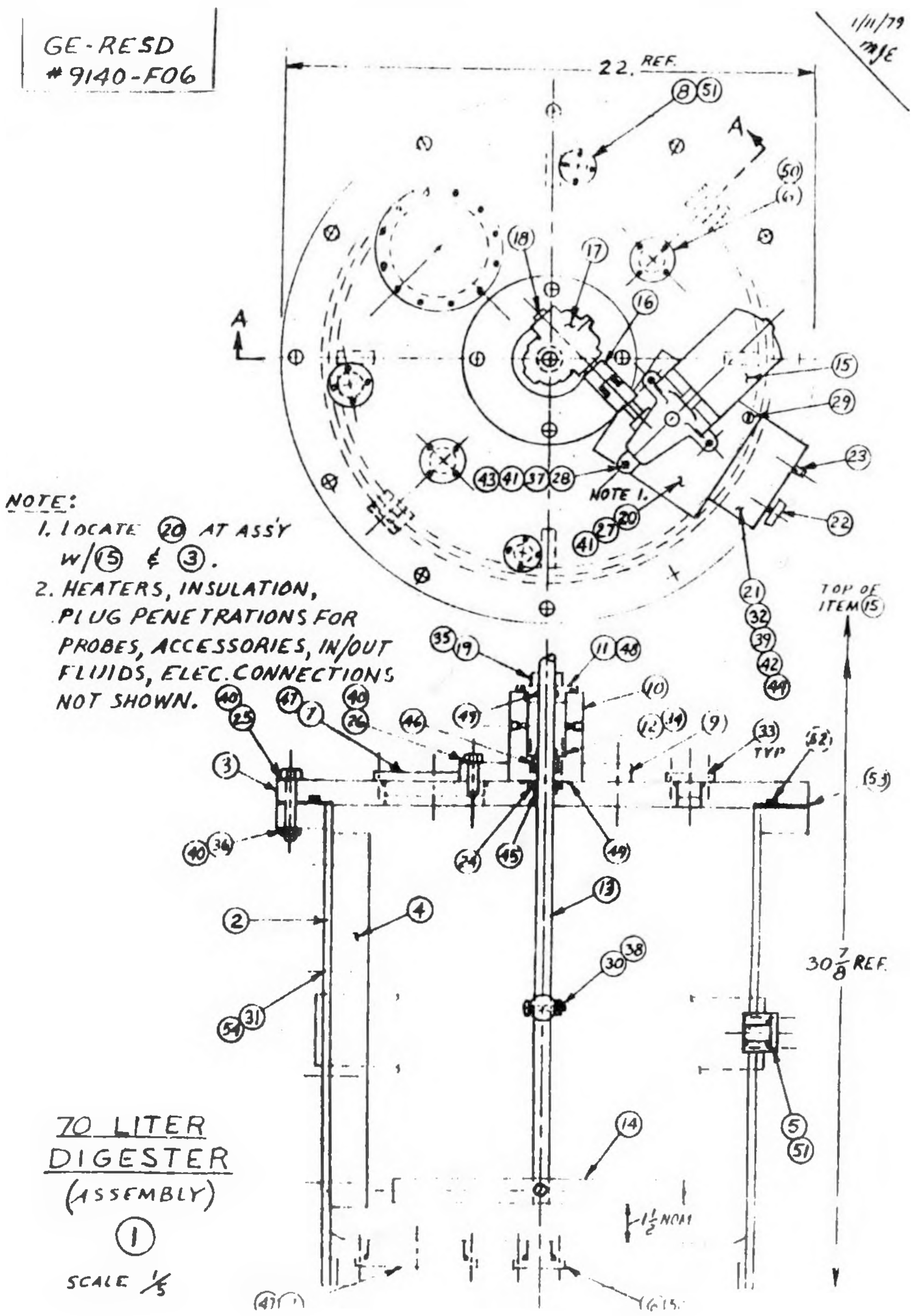


FIGURE 11-B. DIGESTER VESSEL

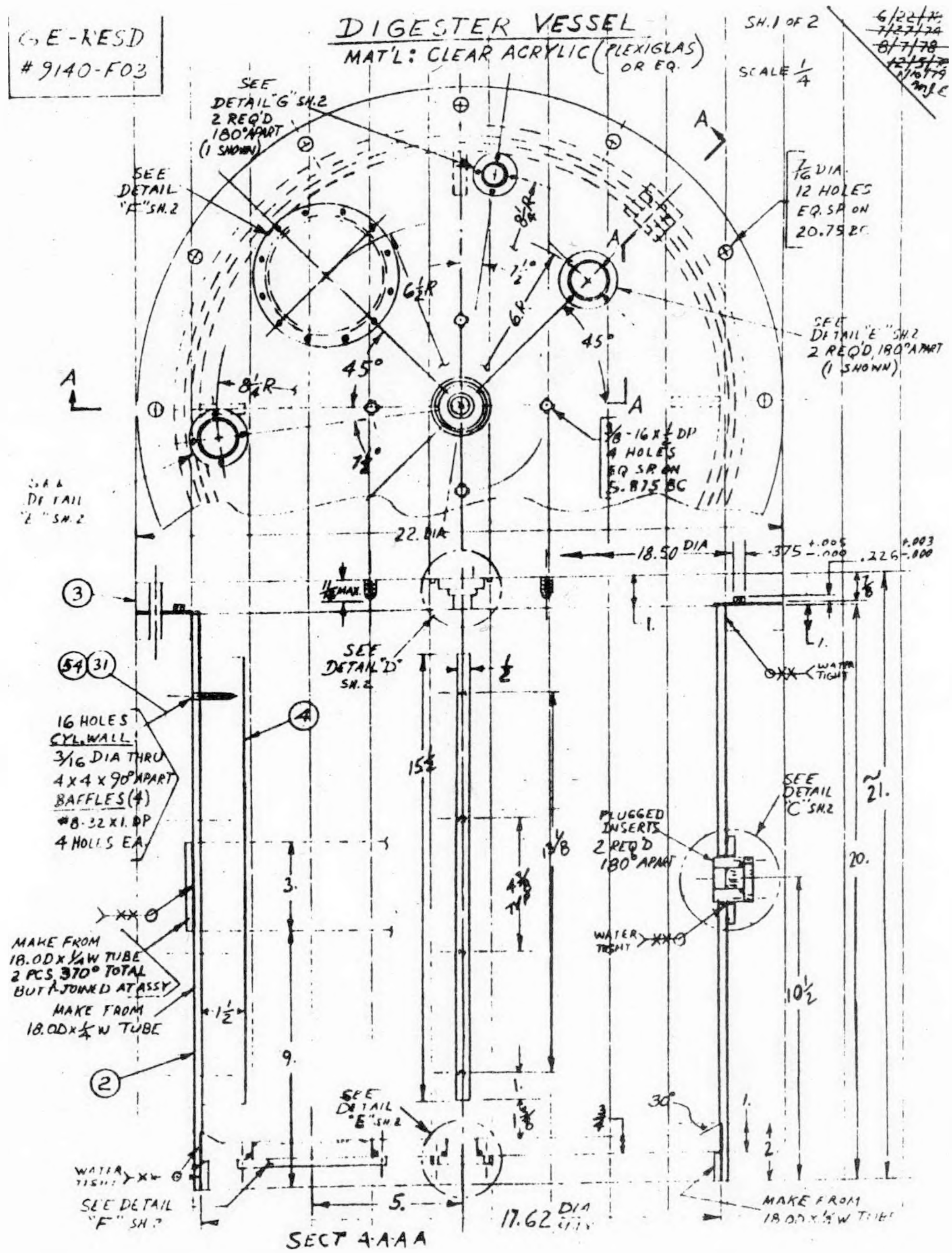
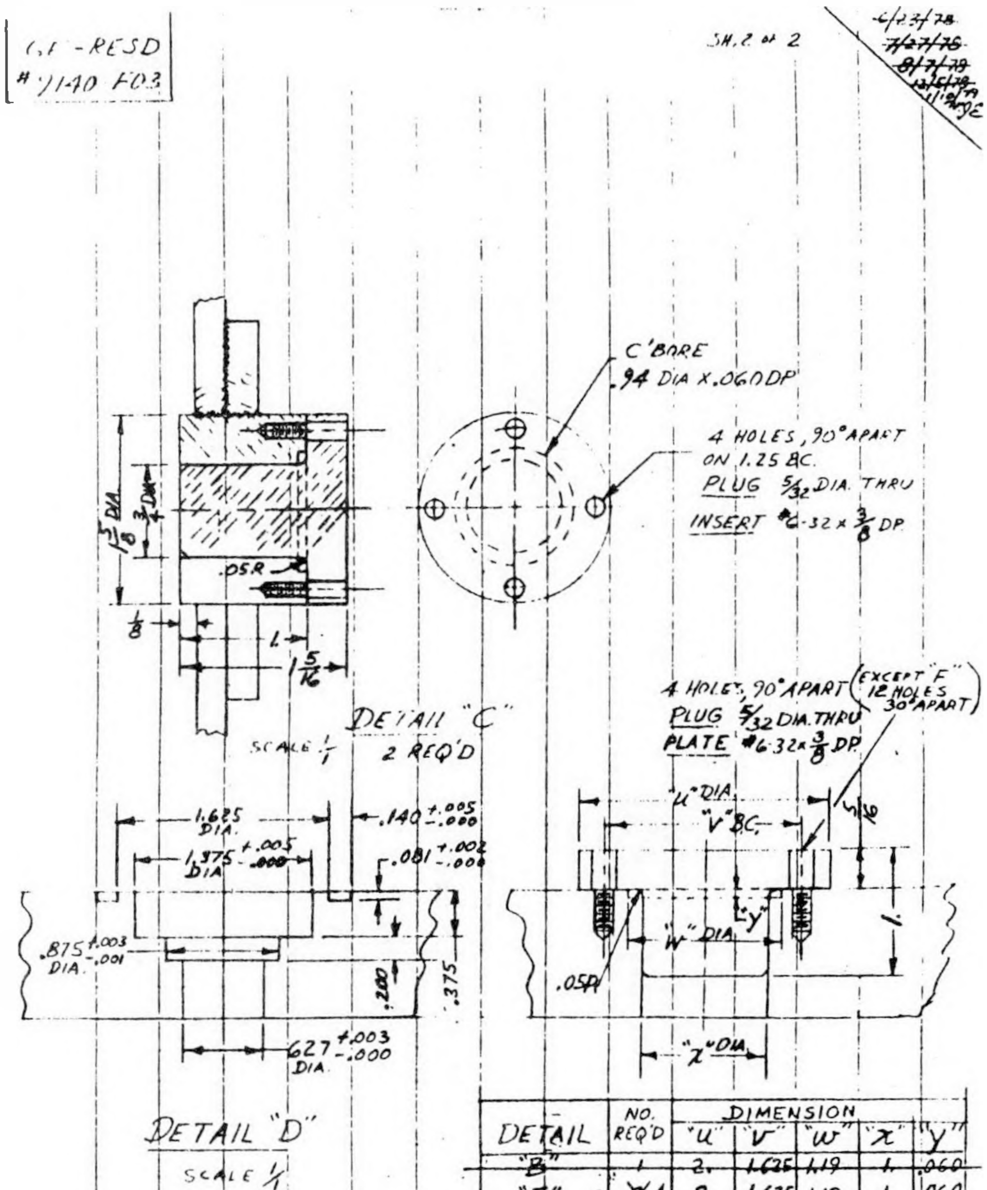


FIGURE 11-C. DIGESTER VESSEL DETAILS



DETAIL	NO. REQ'D	DIMENSION "U"	"V"	"W"	"X"	"Y"
~~"B"~~	~~1~~	~~2.~~	~~1.625~~	~~1.19~~	~~1.~~	~~.060~~
"E"	~~3~~ 4	2.	1.625	1.19	1.	.060
"F"	2	5.	4.688	4.19	4.	.060
"G"	2	1 5/8	1.250	.94	3/4	.060

FIGURE 11-3. DIGESTER - PACKING WELL COMPONENTS

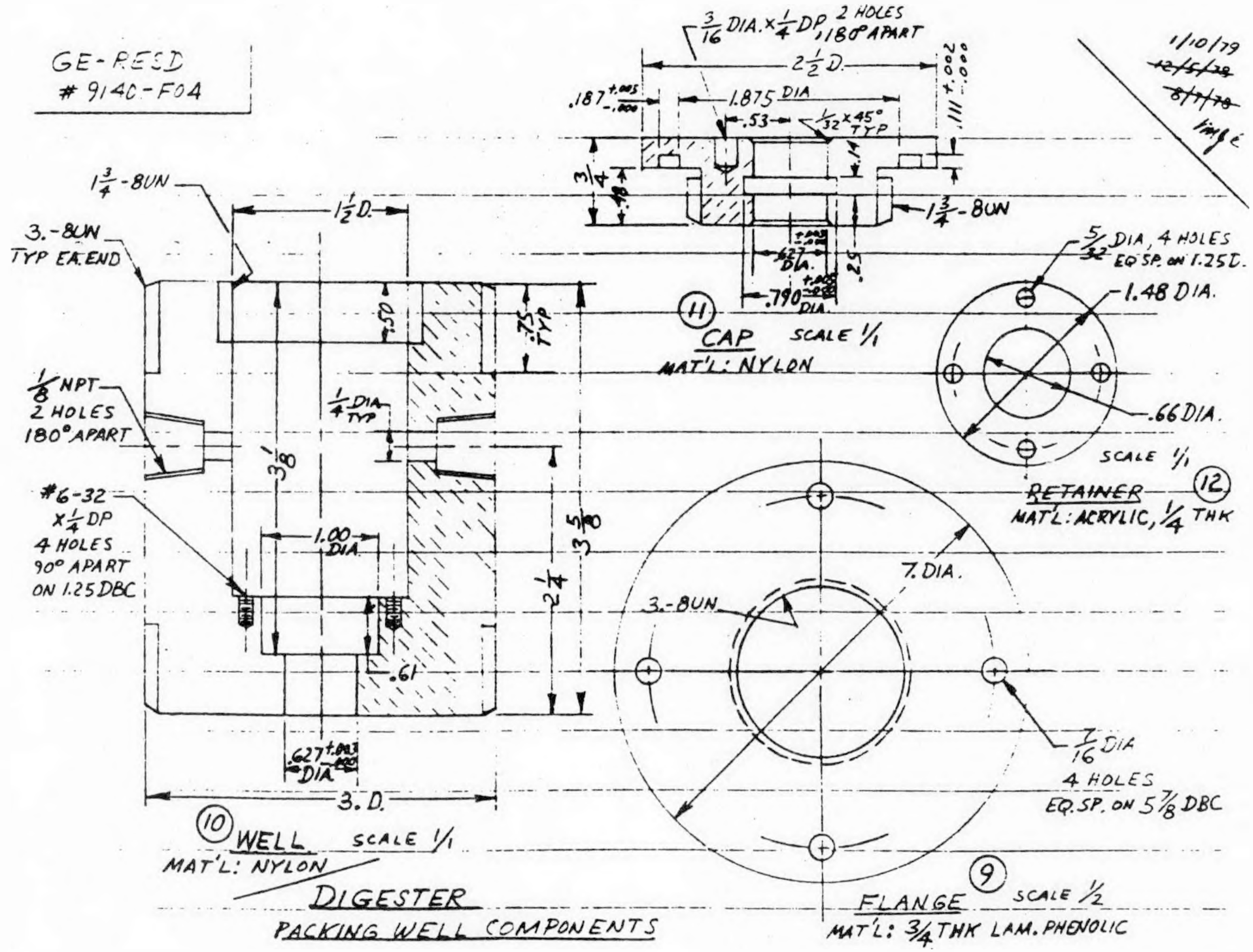


FIGURE 11-E. DIGESTER DRIVE COMPONENTS

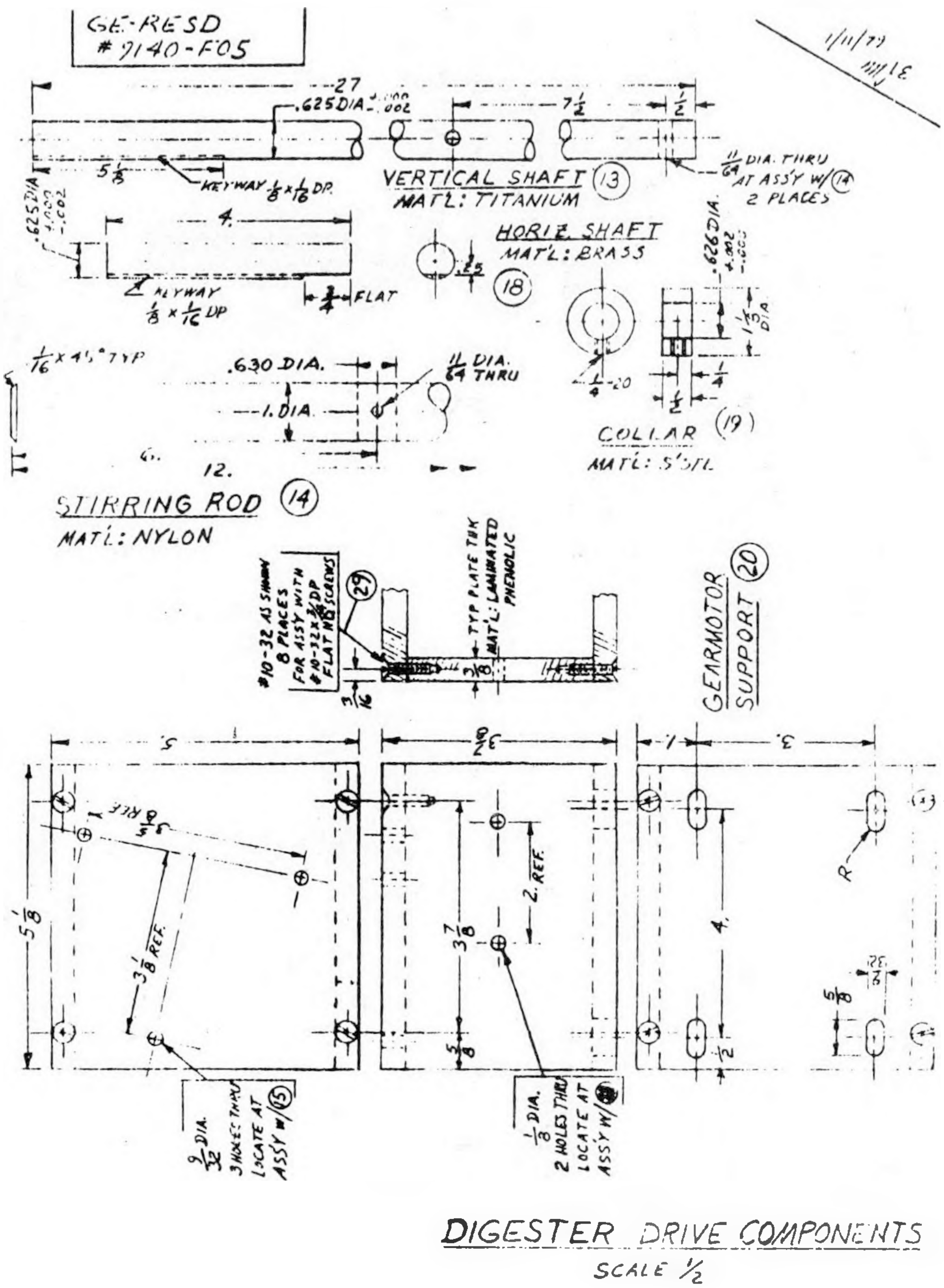


TABLE 14. 70-LITER DIGESTER

LIST OF PARTS

Refer to ASSEMBLY Sketch #9140-F06

QTY.	ITEM NO.	ITEM	IDENT./DESCRIP.	MATERIAL
-	1	ASSEMBLY	9140-F06	
1	2	VESSEL	9140-F03	Clear Acrylic
1	3	COVER		
4	4	BAFFLE		
2	5	PLUG	Detail "C"	
4	6	PLUG	"E"	
2	7	PLUG	"F"	
2	8	PLUG	"G"	
1	9	FLANGE	9140-F04	Laminated Phenolic
1	10	WELL		Nylon
1	11	CAP		
1	12	RETAINER		Acrylic
1	13	SHAFT, VERTICAL	9140-F05	Titanium
2	14	ROD, STIRRING		Nylon
1	15	GEARMOTOR	W.W. Grainger, StK#2Z802 11/15 HP, AC/DC, Rt.Angle Dr. 50 rpm @ 45 in-lb FLT	
1	16	COUPLING	W.W. Grainger, StK#s 4x176, 4x177, 1x409, 3 Pc. Flexible 1/2" to 5/8"	
1	17	GEAR DRIVE	Tol-O-Matic, Model #0110 RH Rt. Angle, 5/8"x5/8", w/Keys	
1	18	SHAFT, HORIZONTAL	9140-F05	Brass
2	19	COLLAR		S'Stl.
1	20	SUPPORT, GEARMOTOR		Laminated Phenolic
1	21	BOX, ELEC. JUNCT.	Dbl. Switch Plate 4x4x2-1/4	Galv. Stl.
1	22	CONTROL SPEED	W.W. Grainger, StK#4x796 5 amp. (for Item 15)	
1	23	SWITCH	Sgl. Pole, 15a, 125v, AC/DC	
1	24	BEARING	Fafnir Bearing #S7PP Radial, Sealed, 5-inch Ser. .625"B x 1.375" OD x .3438"W	
12	25	BOLT, HEX HD	1/8-16 UNC x 2-1/2 Lg	S'Stl.
4	26	BOLT, HEX HD	3/8-16 UNC x 1-1/4 Lg	
4	27	SCREW, HEX HD	1/4-20 UNC x 3/4 Lg	

QTY.	ITEM NO.	ITEM	IDENT./DESCRIP.	MATERIAL
3	28	SCREW, RD HD	1/4-20 UNC x 1-1/4 Lg	S'Stl.
8	29	SCREW, FLAT HD	#10-24 UNC x 3/4 Lg	
2	30	SCREW, PAN HD	#8-32 UNC x 1-1/4 Lg	
16	31	SCREW, PAN HD	#8-32 UNC x 1. Lg	
2	32	SCREW, PAN HD	#6-32 UNC x 3/4 Lg	
56	33	SCREW, PAN HD	#6-32 UNC x 5/8 Lg	
4	34	SCREW, SOC HD CAP	#6-32 UNC x 3/8 Lg	
2	35	SCREW, HDLS SET	1/4-20 UNC x 1/4 Lg	Brass
12	36	NUT, HEX	3/8-16 UNC	S'Stl.
3	37	NUT, HEX	1/4-20 UNC	
2	38	NUT, HEX	#8-32 UNC	
2	39	NUT, HEX	#6-32 UNC	
28	40	WASHER, FLAT	3/8	
7	41	WASHER, FLAT	1/4	
2	42	WASHER, FLAT	#6	
3	43	WASHER, LOCK	1/4	
2	44	WASHER, LOCK	#6	
1	45	SEAL, SHAFT	BAL-SEAL, SIZE #208 Ser. OR-305 .625 ID x .875A x 1/8W	
1	46	PACKING, SHAFT	Halogen Insul. & Seal Style 409 FM, Pkg Set .625 ID x 1.00 OD x L_3= .61	
2	47	O-RING	-45	Buna-N, 50-70 Dur.
1	48	O-RING	-225	
1	49	O-RING	-114	
4	50	O-RING	-22	
4	51	O-RING	-18	
1	52	O-RING(Optional if Item 53 used)	-466	
1	53	GASKET	22 OD x 18 ID x 1/8 Thk	Butyl or Silicone Rubber, 50 Dur.
AR	54	SEALANT	GE, RTV Silicone Rubber Liquid Sealant	

As of the date of this report, one digester has been completed, tested and shipped to IGT. The second digester is in the final stages of checkout and is scheduled for shipment to WRRC in the latter part of January 1979.

In conjunction with this task, an auto feeder system for the introduction of kelp feed to these larger digesters is in the design phase. This system, when completed, will provide the semi-continuous/continuous feeding operations required for steady-state operational data.

XI. CHANGE OF SAMPLE pH ON FREEZE/THAW

During a period when our pH meter was inoperable, some experimental digester samples were frozen for later analyses. After thawing, the pH values of these samples appeared to be inconsistent with previous data. As such, the pH of several fresh fermenter samples was determined prior to and after freeze/thaw. It was found under these conditions that pH values increased by an average of 0.6 pH units (≃pH 6.6 to ≃pH 7.2). Although the exact mechanism of this shift is not known, it probably involves a loss of volatile acids or CO_2 upon thawing. One is thus cautioned on interpretation of data obtained on frozen samples unless care is taken to prevent losses due to volatilization (i.e., storage in sealed vials with limited head space).

XII. PRESENTATIONS/MEETINGS

The following is a list of presentations made during the past year in conjunction with the Marine Biomass Program:

FEBRUARY
- GRI Review Meeting, Newport Beach, Calif.

MARCH
- AIChE, Delaware Valley Section, Philadelphia, Pa. Paper entitled "A research and development program to assess the technical and economic feasibility of methane from giant brown kelp."
- GRI Project Advisors review, King of Prussia, Pa.

MAY
- American Society for Microbiology, Annual Meeting, Las Vegas. Paper entitled "Alginate utilization by marine anaerobes."

JUNE • GRI Project Advisors Review, King of Prussia, Pa.

JULY • GRI Project Advisors Review, Newport Beach, Calif.

AUGUST • Prime Workshop, Villanova University. Paper entitled, "Production of substitute natural gas from marine biomass."

SEPTEMBER • GRI Research Coordination Panel, Newport Beach, Calif.

NOVEMBER • GRI/EPRI Meeting, Santa Clara, Calif.

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APPENDIX

MEDIA FORMULATIONS

A. Calcium Acetate Enrichment (Baresi *et al*., 1978)

Tap Water	1 liter
NH_4Cl	1 gm
K_2HPO_4	0.4 gm
$MgCl_2 \cdot 6H_2O$	0.1 gm
$CaCO_3$	100 gm
Calcium Acetate	20 gm
1% Resazurin	1 ml
NaCl	30 gm (GE Modification)

Boil and cool under N_2.

Adjust pH with HCl to pH 6.5-6.6.

Dispense under N_2 and sterilize.

Before inoculation, add 3 ml/100 of sterile

1% $Na_2S \cdot 9H_2O$ in 5% Na_2CO_3.

Final pH should be pH 7.0-7.1.

B. Calcium Butyrate Enrichment

Identical to calcium acetate medium above except substitute 10 gm/l calcium butyrate for calcium acetate.

C. FAS (Ferry et al., 1974)

Distilled water	1 liter
K_2HPO_4	230 mg
KH_2PO_4	230 mg

$(NH_4)_2SO_4$	230 mg	
NaCl	30 gm	(GE Modification)
$MgSO_4 \cdot 7H_2O$	90 mg	
$CaCl_2 \cdot 2H_2O$	60 mg	
Yeast Extract	2 gm	
Trypticase	2 gm	
Resazurin	1 mg	
Na_2CO_3	4 gm	
Cysteine • HCl	250 mg	
$Na_2S \cdot 9H_2O$	250 mg	
Vitamin Solution	10 ml	(Wolin et al., 1963)
Mineral Solution	10 ml	(Wolin et al., 1963)
Sodium Acetate	2 gm	
Adjust pH to	pH 7.0-7.5	

D. BWS (Balch and Wolfe, 1976; *as modified by GE-RESD)

Distilled H_2O	1 liter
KH_2PO_4	450 mg
K_2HPO_4	450 mg
$(NH_4)_2SO_4$	450 mg
* NaCl	30 gm
$MgSO_4 \cdot 7H_2O$	180 mg

$CaCl_2 \cdot 2H_2O$	12 mg
$FeSO_4 \cdot 7H_2O$	2 mg
Resazurin	1 mg
$NaHCO_3$	2.5 gm
L-cysteine · HCl	500 mg
Sodium Formate	2 gm
Yeast Extract	2 gm
Tryptone	2 gm
Sodium Acetate	2 gm
Isobutyric Acid	0.5 ml
* Valaric Acid	0.5 ml
* Propionic Acid	0.5 ml
Tween 80	0.02 ml
* Vitamin Solution (Wolin _et_ _al_., 1963)	

SECTION III

SYSTEMS ANALYSIS AND DEVELOPMENT

The following analysis (Attachment A) is a first-order assessment of the economics of producing substitute natural gas (SNG) from the anaerobic digestion of giant, California kelp grown on an open ocean farm.

SECTION III - ATTACHMENT A

GAS COST ANALYSIS

OF

SNG PRODUCED FROM ANAEROBIC DIGESTION OF MACROCYSTIS PYRIFERA GROWN IN AN OCEAN FARM

CONTENTS

LIST OF ABBREVIATIONS

A-Y	Acre - Year
BTU	British Thermal Unit
C	Carbon
CC	Cubic Centimeter
DAF	Dry-Ash-Free
DAF-T/A-Y	Dry-Ash-Free Tons per Acre per Year
E	Nutrient Uptake Efficiency
FT	Foot (length)
GMDI	Global Marine Development, Incorporated
HP	Horsepower
HR	Hour
LB V.S.	Pound Volatile Solids
M	Meter (length)
MIN	Minute
MM	Million
N	Nitrogen
nM	Nano-mole
O & M	Operation & Maintenance
P	Phosphorous
PI	Plant Investment
QAM	Quarter Acre Module (Test Farm)
SCF	Standard Cubic Feet
TPI	Total Plant Investment

μG-A N/l	Micro Gram-Atoms per liter Nitrogen
V.S.	Volatile Solids
W	Working Capital
WRRC	Western Regional Research Center (U.S. Department of Agriculture)
YR	Year

PRODUCT COST SUMMARY AND SYSTEM DESIGN PARAMETERS

SUMMARY

FEEDSTOCK & GAS COSTS AS A FUNCTION OF FARM YIELD

FARM YIELD (TONS DAF/ACRE-YR)	FEEDSTOCK UNIT COST ($/MM BTU)	GAS COST ($/MM BTU)
25	3.31	5.68
50	2.38	4.18
70	2.12	3.86
105	1.52	2.97

BASELINE DESIGN PARAMETERS

- 100 SQUARE MILES
- ALGAE COMPOSITION
  - C = 45%
  - N ≤ 1.6%
  - P = 0.3%
- YIELD

TONS ALGAE/ACRE-YR (DAF)	25-105

- ENERGY CONTENT — 8000 BTU/LB (DAF)
- UPWELLING DEPTH — 500'
- WET KELP
  - 7.6% VOLATILE SOLIDS
  - 13.0% TOTAL SOLIDS
- DIGESTION OF RAW KELP AT 23^{o}C
- DETENTION TIME — 6 DAYS
- 70% OF VOLATILE SOLIDS CONVERTED = 5.5 $\frac{SCF}{LB\ V.S.}$ OF METHANE
- 40% CH_4, 60% CO_2 BY WEIGHT
- 65% CH_4, 35% CO_2 BY VOLUME

OCEAN FARM ANALYSIS

FARM YIELD POTENTIAL

CASE 1

STANDING CROP	=	15 WET TONS/ACRE (GERARD 1976)
GROWTH RATE	=	3%/DAY (NEUSHUL & HAXO 1963, WHEELER 1977)*
ANNUAL PRODUCTION	=	329 TONS/A-Y
ANNUAL YIELD (DAF)	=	25 TONS/A-Y

CASE 2

STANDING CROP	=	31 WET TONS/ACRE (GERARD 1976)
GROWTH RATE	=	3%/DAY
ANNUAL PRODUCTION	=	664 TONS/A-Y
ANNUAL YIELD (DAF)	=	50 TONS/A-Y

CASE 3

STANDING CROP	=	43 WET TONS/ACRE (GERARD 1976, NORTH 1957)
GROWTH RATE	=	3%/DAY (NEUSHUL)
ANNUAL PRODUCTION	=	921 TONS/A-Y
ANNUAL YIELD (DAF)	=	70 TONS/A-Y

CASE 4

STANDING CROP	=	64 WET TONS/ACRE
GROWTH RATE	=	3%/DAY
ANNUAL PRODUCTION	=	1380 TONS/A-Y
ANNUAL YIELD (DAF)	=	105 TONS/A-Y

* OBSERVED GROWTH RATES IN NATURAL BEDS

FARM YIELD POTENTIAL

SAMPLE CALCULATIONS

GIVEN:

STANDING CROP WEIGHT = W_o = 31 WET TONS/ACRE

GROWTH RATE = g = 3%/DAY

ASSUME:

HARVEST EVERY 6 WEEKS OR 42 DAYS $\frac{365}{42}$ = 8.7 HARVESTS/YEAR

CALCULATION:

$$\text{PRODUCTION/ACRE - STANDING CROP} = \left[(1+g)^n W_o\right] - W_o = W_o\left[(1+g)^n - 1\right]$$

$g = .03$

n = 42 DAYS

W_o = 31 WET TONS/ACRE

$$\text{PRODUCTION/ACRE - STANDING CROP} = 31\left[(1+.03)^{42}-1\right] = 76.3 \text{ WET TONS}$$

PRODUCTION/ACRE - YR. = 8.7 HARVESTS X 76.3 WET TONS/HARVEST

= 664 WET TONS/ACRE-YR.

DRY-ASH-FREE (DAF) WEIGHT = 7.6% WET WEIGHT

∴ YIELD (DAF) = .076 X 664 = 50 TONS/ACRE-YR.

UPWELLING REQUIREMENT AS A FUNCTION OF NITROGEN DEMAND

HARVESTED DAF TONS/A-Y	YEARLY CROP GROWTH DAF TONS/A-Y	LBS. N/A-Y	GPM/ACRE
25	30	960	1044
50	60	1920	2088
70	84	2688	2924
105	126	4032	3727*

ASSUMPTIONS

- 25 μgA N/1
- 1.6% N
- 60% EFFICIENCY

* REFLECTS REDUCTION BY 15% TO CREDIT RETURN OF DIGESTER EFFLUENT NUTRIENTS TO FARM.

UPWELLING REQUIREMENT - SAMPLE CALCULATIONS

DESIGN PARAMETERS

KELP NITROGEN CONTENT	1.6 WT. % DAF
UPTAKE EFFICIENCY (E)	60%
ANNUAL HARVEST	50 TONS DAF/ACRE
SOURCE NUTRIENT CONCENTRATION	25 μG-A N/LITER
FROND DIEOFF DUE TO HARVEST AND NATURAL PLANT DIEOFF (20% TOTAL)*	10 TONS DAF/ACRE-YR.
ANNUAL CROP GROWTH REQUIRED TO PRODUCE 50 TONS DAF/ACRE-YR (= 50 + TOTAL DIEOFF)	60 TONS DAF/ACRE-YR.
KELP NITROGEN REQUIREMENT @ 1.6%	1920 LBS./ACRE-YR.

UPWELLING FLOW CALCULATION

$$\text{SOURCE NITROGEN SUPPLY} = \frac{\text{KELP NITROGEN REQUIREMENT}}{E} = 3200 \text{ LBS/ACRE-YR}$$

@ 25 μG-A N/LITER, $25 \times 14 \times 10^{-6}$ GMS N/LITER $= 3.5 \times 10^{-4}$ GMS/LITER

$$\text{LB-N/GAL} = 3.5 \times 10^{-4} \frac{\text{GMS}}{\text{LITER}} \times 3.785 \frac{\text{LITERS}}{\text{GAL.}} \times \frac{\text{LB}}{454 \text{ GMS}} = 2.9 \times 10^{-6}$$

$$\text{OR } \frac{\text{GAL}}{\text{LB-N}} = 3.43 \times 10^{5}$$

$$\text{FOR ONE ACRE: GAL/MIN} = (\text{LBS-N/YR}) \times \left(\frac{\text{GAL}}{\text{LB-N}}\right) \times \frac{\text{YR.}}{525{,}600 \text{ MIN}}$$

$$@ \ 3200 \text{ LBS/YR., GAL/MIN} = \frac{3200 \times 3.43 \times 10^{5}}{5.256 \times 10^{5}} = 2088$$

* ESTIMATE PER W. NORTH, 2/2/78

NITROGEN UPTAKE ANALYSIS

ASSUME:

SINKING RATE* = .004 KT = .0067 FT/SEC

CONCENTRATION (C_0 = 25 nM/CC)

UPTAKE (9/23 CURVE) = 55 nM/CM^2/HR

RESIDENCE TIME IN 1ST METER = 0.135 HR

$$\therefore \; 55 \frac{nM}{HR} \times 0.135\ HR = 7.43\ nM = R_1$$

IN FIRST METER OF TRAVEL

$C_1 = C_0 - 7.43\ nM = 17.6\ nM/CC$

UPTAKE = 48.5 nM/CM^2/HR @ C_1 = 17.6 nM/CC

$$\therefore \; 48.5 \frac{nM}{HR} \times .135\ HR = 6.48\ nM = R_2$$

IN SECOND METER OF TRAVEL

REMOVAL EFFICIENCY IN FIRST TWO METERS

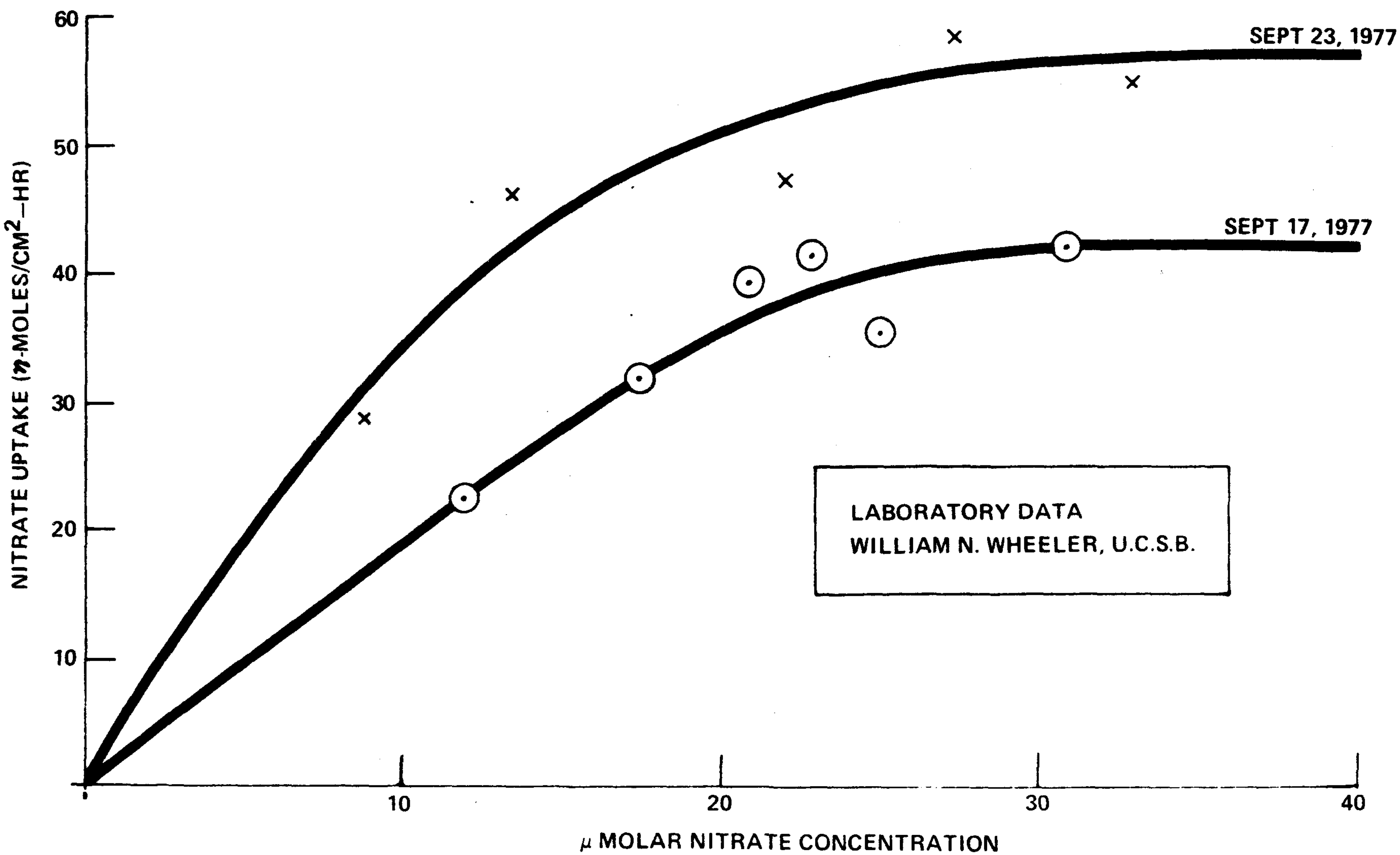
$$\% = \frac{R_1 + R_2}{C_0} \times 100$$

$$= 56\%$$

FOR OVERALL REMOVAL EFFICIENCY (TOTAL FARM) ASSUME 60%

* BASED ON DATA FROM OFEF FINAL REPORT (NUC) BY HOFFMAN, STRICKLAND, HARVEY - JULY 1967, SUBTASK 4, VOLUME 2

MACROCYSTIS NITRATE UPTAKE AS FUNCTION OF NITRATE CONCENTRATION (LABORATORY DATA)



POWER REQUIREMENT FOR UPWELLING

DESIGN PARAMETERS

DENSITY HEAD	0.8 FT H_2O (1)
FRICTION LOSS	1.0 FT H_2O (APPROX.) (2)
DISTRIBUTION LOSS	3.0 FT H_2O (2)
TOTAL HEAD (h_t)	4.8 FT H_2O

ANNUAL PRODUCTION (DAF TONS/A-Y)	25	50	70	105
UPWELLING RATE (GPM)	1044	2088	2924	3727
POWER INPUT (100% EFFICIENCY) (HP/ACRE) (3)	1.3	2.6	3.6	4.6
UPWELLING PUMP EFFICIENCY		50-90%		
POWER REQUIREMENT (HP/ACRE) @ 70% EFFICIENCY	1.8	3.7	5.1	6.6
POWER REQUIREMENT (HP/64,000 ACRES) X 10^5	1.2	2.4	3.3	4.2
POWER REQUIREMENT (BTU/YR) X 10^{12} (4)	2.7	5.3	7.4	9.4
FARM OUTPUT - (BTU/YR) X 10^{12}	26	51	72	108
% FARM OUTPUT REQUIRED	10	10	10	9

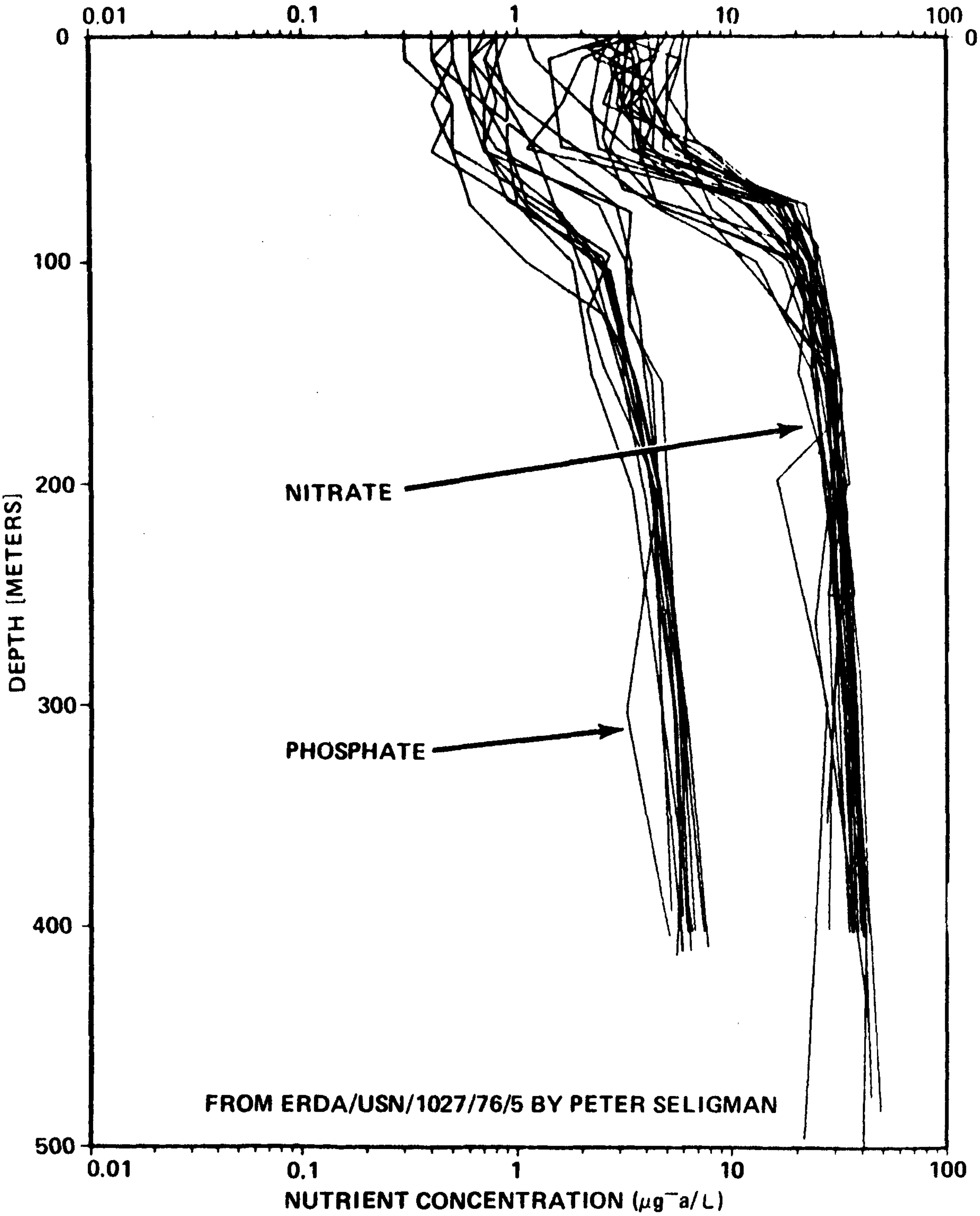
(1) REFERENCE ISC FINAL REPORT - VOLUME [illegible]

(2) PRACTICAL DESIGN GOALS EST[illegible] ANALYSIS

(3) HP = (1.214 X 10^{-3}) [illegible]

(4) BTU/YR = (2.23 X [illegible]

AREA TWELVE - WINTER



NUTRIENTS VS. DEPTH OBSERVED IN
MONTEREY, CALIFORNIA AREA

FARM CAPITAL INVESTMENT SUMMARY

($ MM)

FARM PRODUCTION (DAF TONS/A-Y)	25	50	70	105*
SUBSTRATE	75	75	75	56
NUTRIENT SUPPLY	153	244	324	328
HARVESTING	75	125	175	225
POSITIONING	31	31	31	31
SUPPORT	11	11	11	11
TOTAL	345	486	616	651

* ASSUMES: REDUCTION IN UPWELLING PIPE COST FOR VOLUME BUY, DECREASED UPWELLING RATE BY USE OF DIGESTER EFFLUENT AS FARM FERTILIZER, USE OF SUBSTRATE CORNER BUOYS AS UPWELLING BUOYS.

CAPITAL INVESTMENT

NUTRIENT SUPPLY

($ MM)

FARM PRODUCTION (DAF TONS/A-Y)	25	50	70	105
UPWELLING PIPES	85	146	195	157*
DISTRIBUTION PIPES	25	41	62	92
PUMPS	9	17	24	29
SUPPORT BUOYS	34	40	43	50
TOTAL	153	244	324	328

* REFLECTS 30% COST DISCOUNT FOR VOLUME BUY.

SAMPLE CALCULATION - NUTRIENT SUPPLY CAPITAL INVESTMENT

EXAMPLE FOR 50 TON DAF/A-Y FEEDSTOCK YIELD

C.I. = UPWELLING PIPE COST + DISTRIBUTION SYSTEM COST + SUPPORT BUOY COST + PUMP COST

PIPE COST (ASSUME ONE 500 FT. PIPE FOR 50 ACRES OR 1280 PIPES TOTAL)

CALCULATE PIPE SIZE FOR APPROX. FRICTION HEAD OF 1.0 FT. H_2O:

FLOW RATE (Q) = A X V = 231 FT^3/SEC AT 2088 GPM AVG.

CALCULATE V = Q/A FOR 5.8 FT. DIA. PIPE:

V = 8.75 FT/SEC

CALCULATE REYNOLDS NO.:

$R_e = 4.23 \times 10^6$

FIND f FROM MOODY DIAGRAM FOR SMOOTH PIPE:

f = .0091

CALCULATE FRICTION HEAD $h = f \frac{L}{D} \frac{V^2}{2g}$:

h = .932 FT. H_2O (ACCEPTABLE)

THEREFORE: USE 5.8 FT. DIA. PIPE, 3.0 IN. WALL

CALCULATE VOLUME/FT. OF POLYETHYLENE REQUIRED = 4.553 FT^3/FT

IF SPECIFIC GRAVITY = 0.95, MASS/UNIT VOL. = .95 X 62.4 = 59.28 LBS/FT^3

OR 4.553 X 59.28 = 270 LBS/FT

GIVEN MATERIAL COST = $0.85/LB*:

COST/FT. = 270 X 0.85 = $229.50/FT

COST/PIPE = $229.50 X 500 FT. = $114,750

TOTAL PIPE COST = $114,750 X 1280 PIPES = $146 MM

* DUPONT COST INPUT FOR QAM 2/78

SAMPLE CALCULATION - NUTRIENT SUPPLY CAPITAL INVESTMENT (CONT'D.)

DISTRIBUTION SYSTEM

ASSUME 400 FT. SPACING BETWEEN PIPES

THEN TOTAL DISTRIBUTION PIPE LENGTH = 7 X 10^6 FT.

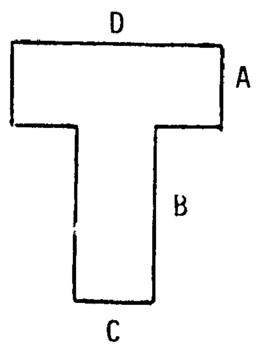
CHOOSE MATERIAL EQUIVALENT OF 14 IN. DIA. PIPE, 3/8 IN. WALL* FOR 3 FT. DIST. HEAD

CALCULATE POLYETHYLENE VOLUME REQUIRED = 0.8 X 10^6 FT^3

@ $.85/LB., TOTAL COST = $41 MM

BUOY COST

ASSUME SPAR TYPE BUOY CONFIGURATION:



DIMENSIONS:

	A	10 FT.
	B	40 FT.
	C	6 FT.
	D	14 FT.

CALCULATE SURFACE AREA: 1530 FT^2

VOLUME OF STEEL IF 3/8" PLATE: 47.9 FT^3

ADD 10% FOR INTERNAL STRUCTURE: V = 52.68 FT^3

WEIGHT/FT^3 STEEL = 489 LBS.

TOTAL WEIGHT OF BUOY = 489 X 52.68 = 25,762 LBS.

@ $2400/TON, COST PER BUOY = $30,914

TOTAL BUOY COST = $30,914 X 1280 BUOYS = $40 MM

* NOTE: 3/8 IN. WALL SELECTED FOR 25 AND 50 TON CASES; 1/2 IN. WALL FOR 70 AND 105 TON CASES

SAMPLE CALCULATION - NUTRIENT SUPPLY CAPITAL INVESTMENT (CONT'D.)

PUMP COST

UPWELLING NEEDS 2.6 HP/ACRE OR 130 HP/50 ACRES

ASSUME PUMP COST = $100/HP OR $13,000 PER PUMP

TOTAL PUMP COST = $13,000 X 1280 PUMPS = $17 MM

TOTAL NUTRIENT SUPPLY COST

TOTAL	=	PIPES	146 MM
	+	DISTRIBUTION SYS.	$ 41 MM
	+	BUOYS	$ 40 MM
	+	PUMPS	$ 17 MM
			$244 MM

SAMPLE CALCULATION - HARVESTING SYSTEM

HARVESTER DESIGN PARAMETERS (HARVEST 50 DAF TONS/YR)

FARM DISTANCE FROM SHORE:	50 MILES
VESSEL SIZE:	25,500 LONG TONS = 27,500 SHORT TONS
DISPLACEMENT:	34,000 LONG TONS = 37,500 SHORT TONS
FULL LOAD CAPACITY:	10,000 SHORT TONS
SWATH:	100 FT.
HARVESTING SPEED:	3 KNOTS = 18,300 FT/HR = 46 ACRES/HR (100 FT. SWATH)
TRANSIT SPEED:	16 KNOTS = 18.5 MILES/HR.
HARVESTING FREQUENCY:	8.7 HARVESTS/YR. (6 WEEK INTERVALS)

50 TONS DAF/A-Y = 664 WET TONS/A-Y

IF HARVESTED 8.7 TIMES PER YEAR: YIELD = 76 WET TONS/ACRE PER HARVEST

ONE HARVESTER MUST COVER 132 ACRES TO FILL TO CAPACITY (10,000 TONS)

AT 46 ACRES/HR. RATE, 2.9 HOURS REQUIRED FOR FULL LOAD.

TRANSIT TIME: 100 MI. 18.5 MI./HR = 5.4 HOURS (ROUND TRIP)

OFF LOADING: ASSUME 2.5 HOURS PER LOAD

THEREFORE, TIME FOR ONE CYCLE = 2.9 HRS + 5.4 HRS + 2.5 HRS = 10.8 HRS.

IN 24 HRS., SHIP COMPLETES 2.2 CYCLES WHICH INCLUDE 6.4 HOURS OF HARVESTING TIME.

HARVESTER FLEET MUST COVER 1525 ACRES/DAY

(64,000 ACRES X 8.7 HARVESTS/YR. X 1/365 DAYS)

AT 46 ACRE/HR. RATE:

1 SHIP TAKES 33 HRS.
2 SHIPS TAKE 16.5 HRS.
3 SHIPS TAKE 11 HRS.
5 SHIPS TAKE 6.6 HRS.

THEREFORE, A FLEET OF 5 SHIPS IS REQUIRED AT COST OF $25 MM* EACH.

* GMDI ESTIMATE 2/2/78

SAMPLE CALCULATION - CAPITAL INVESTMENT -

SUBSTRATE, POSITIONING AND SUPPORT

SUBSTRATE

FROM ISC ANALYSIS, CAPITAL INVESTMENT FOR 100,000 ACRE FARM IS $95.2 MM. DIRECTLY SCALED CAPITAL INVESTMENT FOR 64,000 ACRE FARM IS $61 MM. A CONTINGENCY FACTOR OF 20-25% CONSIDERED HERE TO COMPENSATE FOR DRAG UNCERTAINTY (USED 23%). THEREFORE, SUBSTRATE CAPITAL INVESTMENT TAKEN AS $61 MM X 1.23 = $75 MM.*

POSITIONING

FROM ISC ANALYSIS, CAPITAL INVESTMENT FOR 100,000 ACRE FARM IS $48.5 MM. DIRECTLY SCALED CAPITAL INVESTMENT FOR 64,000 ACRE FARM IS $31 MM.

SUPPORT

FROM ISC ANALYSIS, CAPITAL INVESTMENT FOR 100,000 ACRE FARM IS $16.3 MM. DIRECTLY SCALED CAPITAL INVESTMENT FOR 64,000 ACRE FARM IS $11 MM.

* NOTE: IN THE 105 TON CASE, A 20% REDUCTION IN THE ISC CORNER BUOY COST WAS ASSUMED TO ACCOUNT FOR REDUNDANCY BETWEEN THE ISC CORNER BUOYS AND THE BUOYS INCLUDED IN THE NUTRIENT SUPPLY SYSTEM IN THIS ANALYSIS

FARM OPERATING COST SUMMARY

($ MM)

FARM PRODUCTION (DAF TONS/A-Y)		25	50	70	105
OPERATING LABOR (2% OF HARVESTER COST)*		1.5	2.5	3.5	4.5
MAINTENANCE, LABOR AND SUPPLIES (1.5% OF T.P.I.)*		7.2	10.1	13.0	13.6
FUEL	HARVESTERS	1.0	2.0	2.6	4.1
	POSITIONING	2.0	2.0	2.0	2.0
INSURANCE (1% OF T.P.I.)*		4.8	6.8	8.0	9.1
TOTAL		16.5	23.4	29.1	33.3

* PER GMDI, 2/2/78

FARM TOTAL CAPITAL REQUIREMENT SUMMARY

($ MM)

FARM PRODUCTION (TONS DAF/A-Y)	25	50	70	105
CAPITAL INVEST	345	486	616	651
INSTALLATION (15% OF CAP. INV.)*	52	73	92	98
SUB TOTAL	397	559	708	749
CONTRACTOR & ENGINEERING FEE (5%)*	20	28	35	37
SUB TOTAL CAPITAL INVEST.	417	587	743	786
CONTINGENCY (15%* SUB TOTAL CAP. INVEST.)	63	88	111	118
TOTAL PLANT INVEST.	480	675	854	904
WORKING CAPITAL (2% T.P.I.)	10	14	17	18
INTEREST DURING CONSTRUCT. (18% T.P.I.)	86	121	154	163
START UP (20% OP. COSTS)	3	5	6	7
TOTAL CAPITAL REQ'T.	579	815	1031	1092

* PER GMDI - 2/2/78

FEEDSTOCK UNIT COST CALCULATION

$$\text{FEEDSTOCK UNIT COST} = \frac{\text{FARM TOTAL ANNUAL COST}}{\text{ANNUAL GAS PRODUCTION (100\% CONVERSION EFFICIENCY)}}$$

$$T = \text{TOTAL FARM ANNUAL COST} = N + 0.05\,(C-W) + .005\left[P + \frac{T}{I-T}\,(I-D)R\right](C + W)$$

N = FARM NET OPERATING COST

0.05 = 20 YR STRAIGHT LINE DEPRECIATION

C = FARM TOTAL CAPITAL REQUIREMENT

W = WORKING CAPITAL

D = DEBT FRACTION (75%)

I = INTEREST ON DEBT (9%)

R = RETURN ON EQUITY (15%)

P = DI + (1-D)R (10.5%)

T = TAX RATE (48%)

$$\frac{T}{I-T} = (I-D)R = \frac{48}{52}\,(1-.75)\,15 = 3.46$$

$$\left[P + \frac{T}{I-T}\,(I-D)R\right] = [10.5 + 3.46] = [13.96]$$

$$\therefore\ T = N + .05\,(C-W) + .005\,[13.96]\,(C+W)$$

$$\boxed{T = N + .05\,(C-W) + .0698\,(C+W)}$$

SAMPLE CALCULATION FOR 50 TONS DAF/ACRE-YR:

N = \$ 23.4 MM
C = \$815 MM
W = \$ 14 MM

$$T = 23.4 + .05\,(801) + .0698\,(829) = \$121.3\ \text{MM}$$

ANNUAL GAS PRODUCTION = 8000 BTU/LB. X 50 TONS/A-Y X 64,000 ACRES X 2000 LB/TON = 51×10^{12} BTU/YR

$$\text{COST} = \frac{\$121.3 \times 10^{6}}{51 \times 10^{6}\ \text{MM BTU}} = \$2.38/\text{MM BTU}$$

GAS PRODUCTION SYSTEM ANALYSIS

GAS PRODUCTION SYSTEM YIELD POTENTIAL

GAS PRODUCTION SYSTEM INPUT (TONS DAF/ACRE-YR)	GAS PRODUCTION SYSTEM OUTPUT (BTU/YR X 10^{12})	
	GROSS	NET
25	20.1	17.6
50	40.2	35.2
70	56.3	49.3
105	84.4	73.9

GAS PRODUCTION YIELD - SAMPLE CALCULATION

BASIS: 50 DAF T/ACRE-YR

$= (50)(64000)\ \frac{\text{TONS DAF SOLIDS}}{\text{YR}}$	FARM SIZE = 64000 ACRES
$= (50)(64000)(0.7)\ \frac{\text{TONS GASES}}{\text{YR}}$	70% OF DAF SOLIDS CONVERTED TO GASES
$= (50)(64000)(0.7)(0.4)\ \frac{\text{TONS } CH_4}{\text{YR}}$	40% OF GASES BY WEIGHT IS CH_4
$= (50)(64000)(0.7)(0.4)(2000)\ \frac{\text{LBS } CH_4}{\text{YR}}$	1 TON = 2000 LBS.
$= (50)(64000)(0.7)(0.4)(2000)(1/16)\ \frac{\text{LB MOLES } CH_4}{\text{YR}}$	16 LBS CH_4 = 1 LB MOLE
$= (50)(64000)(0.7)(0.4)(2000)(1/16)(359)\ \frac{\text{SCF}}{\text{YR}}$	1 LB MOLE = 359 SCF
$= (50)(64000)(0.7)(0.4)(2000)(1/16)(359)(10^3)\ \frac{\text{BTU}}{\text{YR}}$	1000 BTU/SCF
$= 40.2 \times 10^{12}\ \frac{\text{BTU}}{\text{YR}}$	

GAS PRODUCTION SYSTEM CAPITAL INVESTMENT SUMMARY

($ MM)

FARM PRODUCTION (TONS DAF/A-Y)	25	50	70	105
LAND	0.25	0.5	0.7	1.1
TRANSPORTATION	12.5	25.0	35.0	52.5
GRINDING	0.66	1.3	1.8	2.8
DIGESTION	23.0	46.0	64.5	96.7
GAS CLEANUP/COMPRESSION	7.9	15.8	22.1	33.2
TOTAL CAPITAL INVESTMENT	44.3	88.6	124.1	186.3

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DIGESTER CAPITAL INVESTMENT SUMMARY AND SAMPLE CALCULATION

(50 DRY TON/ACRE-YR.)

ANNUAL RAW KELP MASS FLOW = 664 WET TONS/ACRE

= $(664)(64000) = 42.5 \times 10^6$ WET TONS

DAILY RAW KELP MASS FLOW = $\frac{42.5 \times 10^6}{365} = 11.6 \times 10^4$ WET TONS

DIGESTER DETENTION TIME = 6 DAYS

REQUIRED DIGESTER CAPACITY = $(6)(11.6 \times 10^4) = 69.6 \times 10^4$ TONS

ASSUMING RAW GROUND KELP DENSITY OF 60 LBS/FT^3,

DIGESTER CAPACITY = $\frac{69.6 \times 10^4}{60} \times 2000 = 23.2 \times 10^6$ FT^3

AT \$2/FT^3 FOR INSTALLED DIGESTER COST,*

DIGESTER COST = $(23.2 \times 10^6)(2) =$ \$46 MM

* Based on inputs from Day and Zimmerman (Philadelphia A&E)

GRINDING, TRANSPORTATION, GAS CLEANUP CAPITAL INVESTMENT

AND

SAMPLE CALCULATIONS

- LAND: 330 ACRES @ $1500/ACRE = $0.5 MM

- GRINDERS: $\$12.5 \times 10^3$ FOR 20 TONS/HR (WRRC)

  $= \$55.8 \times 10^3$ FOR 200 TONS/HR USING 0.65 POWER SCALEUP

  NEED 24 UNITS, EACH 200 TONS/HR, TO PROVIDE FOR DAILY CAPACITY OF 11.6×10^4 TONS/DAY

  $\text{COST} = 24 \times 55.8 \times 10^3 = \$1.3\ \text{MM}$

- TRANSPORTATION: 1. 1 MILE BELT TO TRANSPORT 116,000 TONS OF RAW KELP DAILY

  BELT COST = $145/FT TO HANDLE 150 TONS/HR

  NEED 32 UNITS (OR EQUIVALENT) TO PROVIDE FOR DAILY CAPACITY.

  $\text{COST} = (145)\ (32)\ (5280) = \$24.5\ \text{MM}$

  2. 3 FT. DIA. PIPE TO CARRY BACK DIGESTED SLUDGE; 31.2 FT /SEC.; 6.5 FT HEAD LOSS 1 MILE LONG PIPELINE, 3 FT DIAMETER, POLYETHYLENE

  = $0.5 MM

- GAS CLEANUP: $7.2 MM FOR CO_2 REMOVAL PLANT (BENFIELD CORP.)

  $1.1 MM FOR GLYCOL DEHYDRATION PLANT (M. JONES OF PG&E)

  $7.5 MM FOR COMPRESSORS, ETC. ($\$18 \times 10^6$ FOR PLANT FOR COMPRESSING 200 MCFD FROM ATMOS. TO 1000 PSI)

GAS PRODUCTION SYSTEM OPERATING COST SUMMARY, MM $

FARM PRODUCTION (TONS DAF/A-Y)	25	50	70	105
• O&M LABOR @ 250 AT $20,000	3.3	6.6	9.2	13.8
• ADMIN./OVERHEAD @ 60% OF LABOR	2.0	3.9	5.5	8.3
• SUPPLIES @ 2% OF PI	0.7	1.3	1.8	2.8
• LOCAL TAXES, INSURANCE @ 2.7% OF PI	0.8	1.7	2.4	3.6
OPERATING COST	6.8	13.5	18.9	28.5

GAS PRODUCTION SYSTEM - TOTAL CAPITAL REQUIREMENT

($ MM)

FARM PRODUCTION (TONS DAF/A-Y)	25	50	70	105
• CAPITAL INVESTMENT*	44.3	88.6	124.1	186.3
• INTEREST DURING CONSTRUCTION 2 YRS., 9%	8.0	15.9	22.3	33.5
• WORKING CAPITAL, 2% PI, W	0.9	1.8	2.5	3.7
• START UP CAPITAL, 20% OF GROSS OPERATING COST	1.4	2.7	3.8	5.7
TOTAL CAPITAL REQUIRED	54.6	109.0	152.7	229.2

* INSTALLED COST INCLUDING ENGINEERING

TOTAL SYSTEM ECONOMICS SUMMARY

TOTAL SYSTEM (FARM & GAS PRODUCTION) TOTAL CAPITAL REQUIREMENT SUMMARY

FARM YIELD	FARM			GAS PRODUCTION			TOTAL		
(TONS DAF/A-Y)	N	C ($ MM)	W	N	C ($ MM)	W	N	C ($ MM)	W
25	17	579	10	7	54	1	24	633	11
50	23	815	14	13	109	2	36	924	16
70	29	1031	17	19	153	2	48	1184	19
105	33	1092	18	28	229	4	61	1321	23

N = ANNUAL OPERATING COSTS

C = TOTAL CAPITAL INVESTMENT

W = WORKING CAPITAL

GAS UNIT COST CALCULATION

$$\text{GAS UNIT COST} = \frac{\text{TOTAL ANNUAL COST}}{\text{NET ANNUAL GAS PRODUCTION}}$$

$$T = \text{TOTAL ANNUAL COST} = N + 0.05\,(C-W) + .005\left[P + \frac{T}{I-T}\,(I-D)R\right](C+W)$$

N = NET OPERATING COST

0.05 = 20 YR STRAIGHT LINE DEPRECIATION

C = TOTAL CAPITAL REQUIREMENT

W = WORKING CAPITAL

D = DEBT FRACTION (75%)

I = INTEREST ON DEBT (9%)

R = RETURN ON EQUITY (15%)

P = DI + (1-D)R (10.5%)

T = TAX RATE (48%)

$$\frac{T}{I-T} = (I-D)R = \frac{48}{52}\,(1-.75)\,15 = 3.46$$

$$\left[P + \frac{T}{I-T}\,(I-D)R\right] = [10.5 + 3.46] = [13.96]$$

$$\therefore\ T = N + .05\,(C-W) + .005\,[13.96]\,(C+W)$$

$$\boxed{T = N + .05\,(C-W) + .0698\,(C+W)}$$

SAMPLE CALCULATION FOR 50 TONS DAF/ACRE-YR:

N = \$ 36 MM
C = \$924 MM
W = \$ 16 MM

T = 36 + .05 (908) + .0698 (940) = \$147 MM

NET ANNUAL GAS PRODUCTION = GROSS GAS PRODUCTION (40.2×10^{12} BTU/YR) MINUS PROCESS ENERGY (12.6% X GROSS)

$\therefore$ NET ANNUAL GAS PRODUCTION = 35.2×10^{12} BTU

$$\text{GAS UNIT COST} = \frac{\$147 \times 10^{6}}{35.2 \times 10^{6}\ \text{MM BTU}} = \$4.18/\text{MM BTU}$$

NET ENERGY SUMMARY

FARM ENERGY SUMMARY

FARM YIELD (DAF TONS/A-Y)	ENERGY (BTU X 10^{12}) 25	50	70	105
FARM OUTPUT/YR.	26	51	72	108
UPWELLING ENERGY REQUIREMENT	2.7	5.3	7.4	9.3
FUEL ENERGY REQUIREMENTS:				
FOR HARVESTING	1.6	3.3	4.3	6.9
FOR POSITIONING	0.6	0.6	0.6	0.6
TOTAL FUEL ENERGY	2.2	3.9	4.9	7.5

UPWELLING REQUIRES EQUIVALENT OF 10-11% OF FARM OUTPUT ENERGY

FUEL ENERGY REQUIRED IS EQUIVALENT TO 6-8% OF FARM OUTPUT ENERGY

GAS PRODUCTION ENERGY SUMMARY

GAS PRODUCTION SYSTEM INPUT	GAS PRODUCTION SYSTEM GROSS OUTPUT
25 TONS DAF/A-Y	20.1×10^{12} BTU/YR
50	40.2×10^{12}
70	56.4×10^{12}
105	84.4×10^{12}

GRINDING @ 1.1 KW HR/TON RK	0.4% OF GROSS OUTPUT
MIXING @ 0.25 HP/1000 FT^3 OF DIGESTER	0.3%
GAS CLEANUP AND COMPRESSION	9.9%
TRANSPORTATION, ETC.	2.0%
TOTAL PROCESSING ENERGY REQUIRED	12.6%

ENERGY REQUIREMENTS SUMMARY

BIOMASS PRODUCTION

UPWELLING	11%
FUEL	8%
SUB TOTAL	19%

GAS PRODUCTION

GRINDING & MIXING	.7%
GAS CLEAN UP AND COMPRESSION	9.9%
TRANSPORT	2.0%
SUB TOTAL	12.6%

TOTAL SYSTEM 31.6%

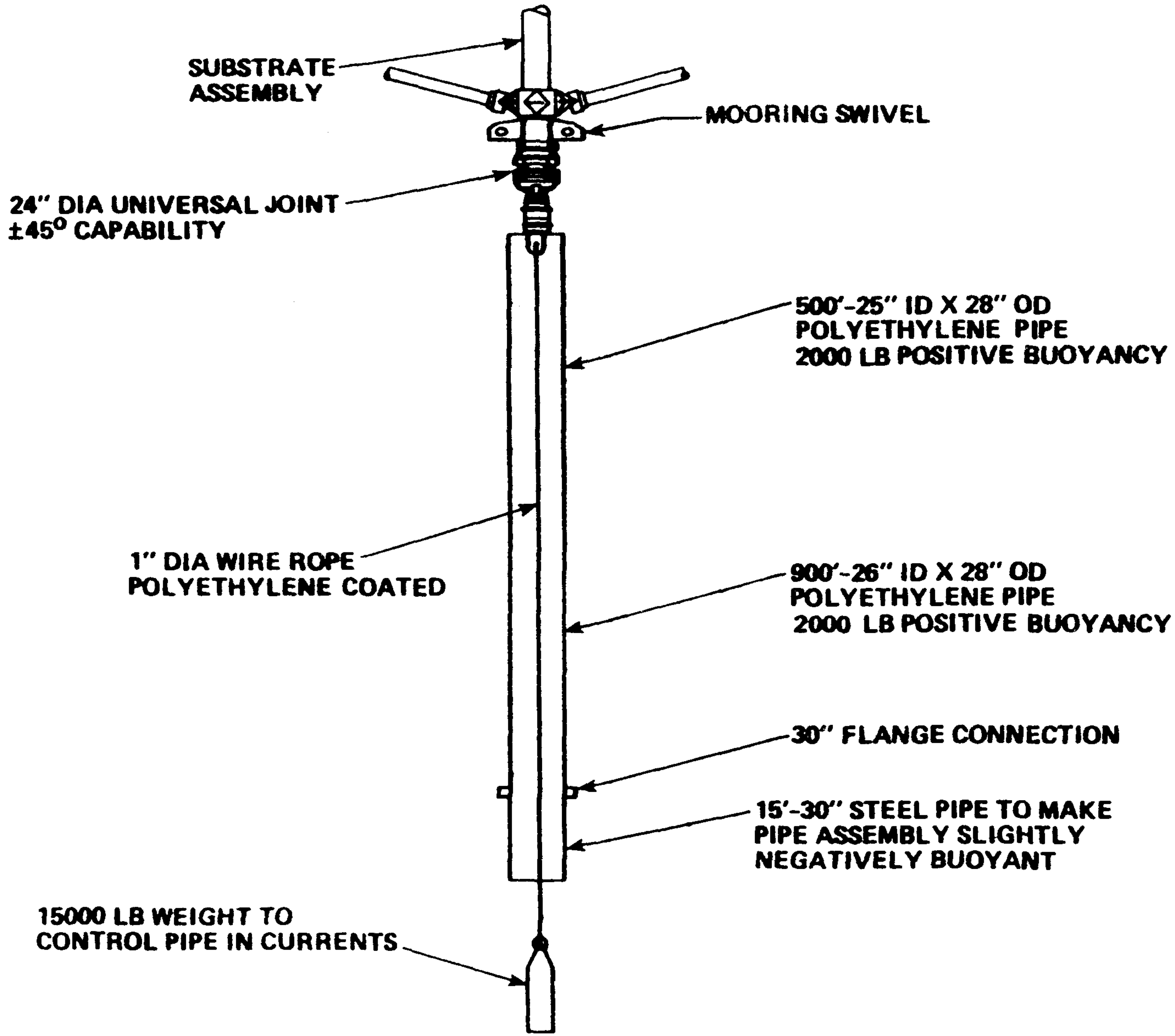
SECTION IV

ENERGY FROM MARINE BIOMASS PROJECT

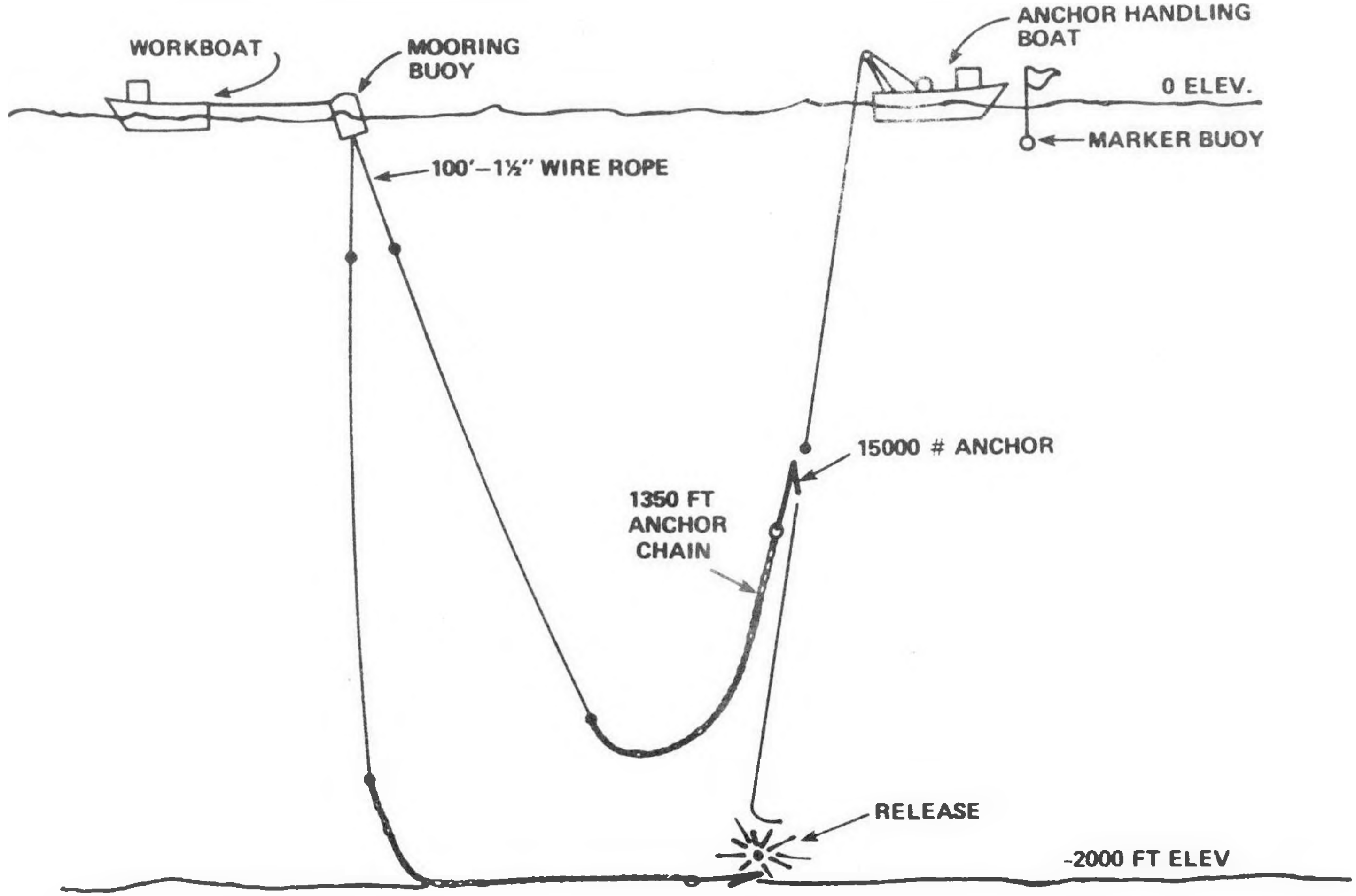
PHOTOGRAPH REVIEW

TEST FARM CONSTRUCTION AND DEPLOYMENT

UPWELLING PIPE



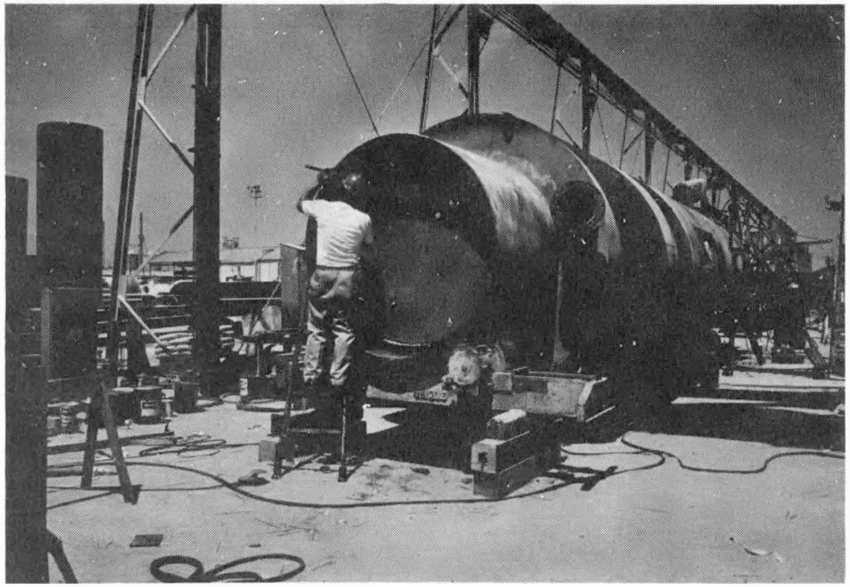
MOORING INSTALLATION



DIVER TRANSPLANTING ADULT MACROCYSTIS TO KELP TEMPORARY STORAGE AREA

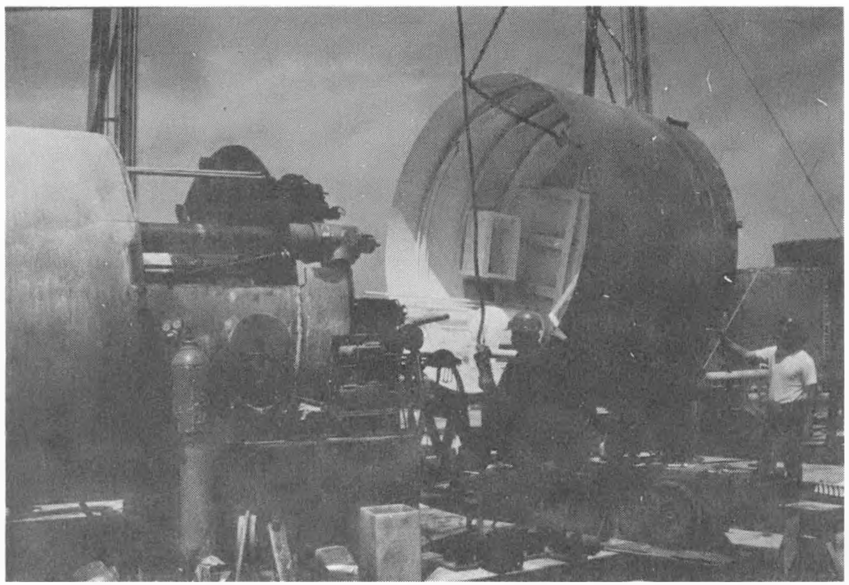
ATTACHMENT OF PLANT TO STORAGE CHAIN AT 45' DEPTH

ATTACHED PLANT AWAITING TRANSPLANT TO TEST FARM

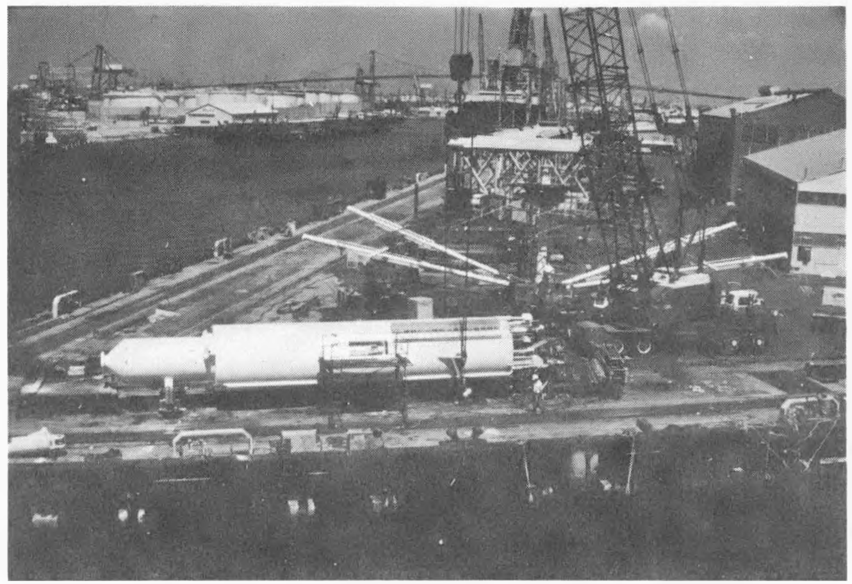


MACHINERY BUOY LOWER END

MACHINERY BUOY SHOWING PUMP COMPARTMENT



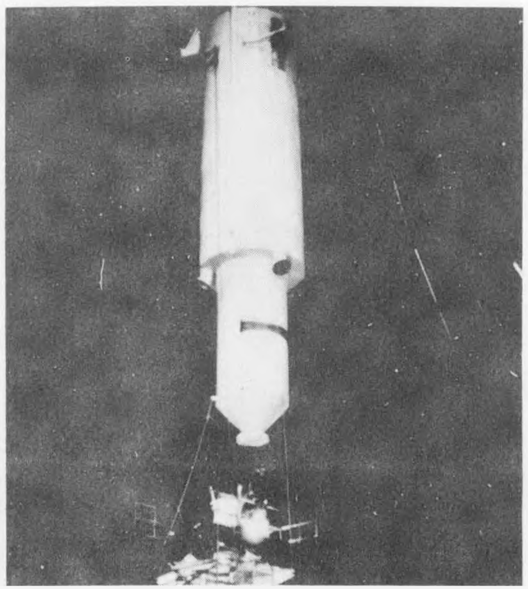
ASSEMBLY OF FINAL UPPER SHELL SECTION
TO MACHINERY BUOY



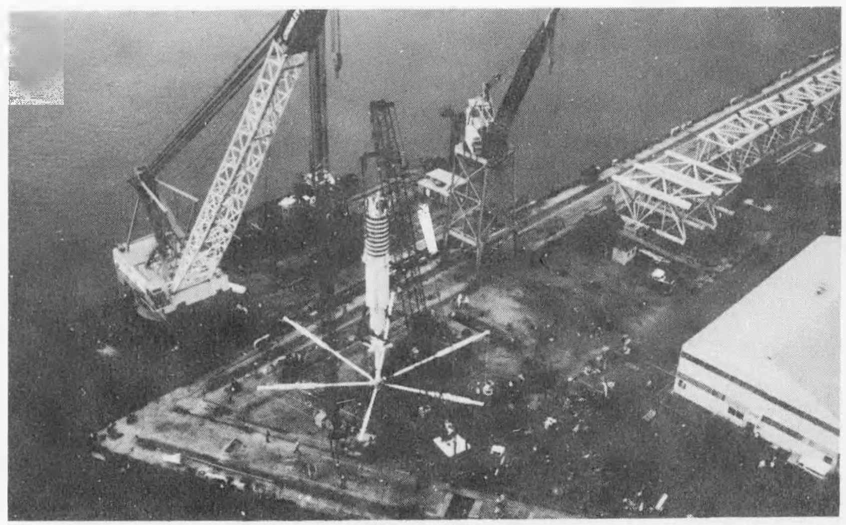
COMPLETED MACHINERY BUOY (FOREGROUND)
SUBSTRATE ASSEMBLY (BACKGROUND)

DRY DOCK TESTING OF MACHINERS BUOY

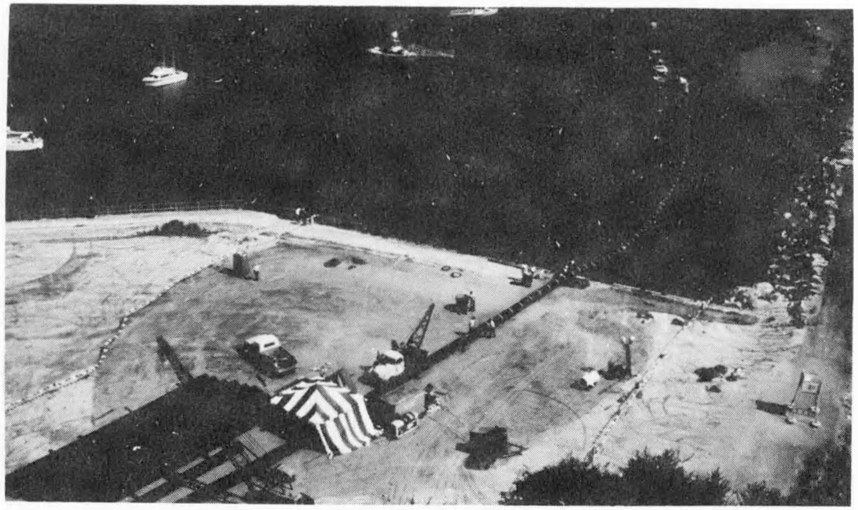
SUBSTRATE ASSEMBLY



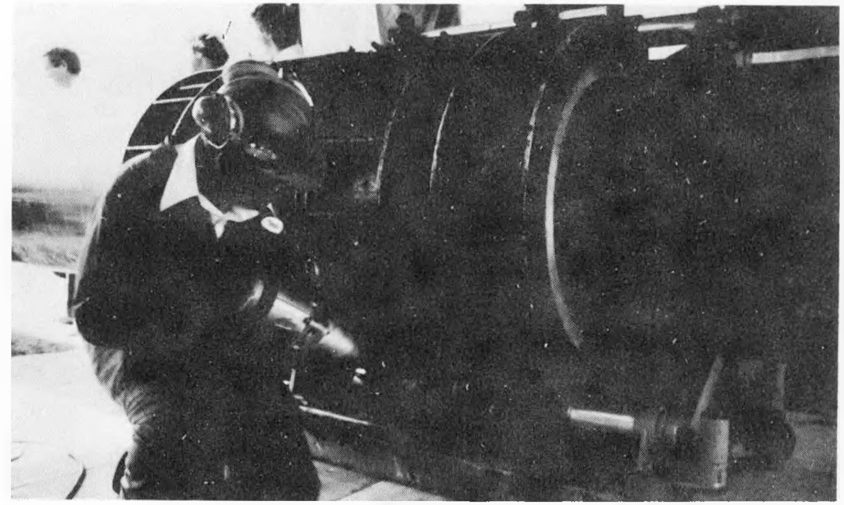
MACHINERY BUOY BEING MATED TO SUBSTRATE ASSEMBLY



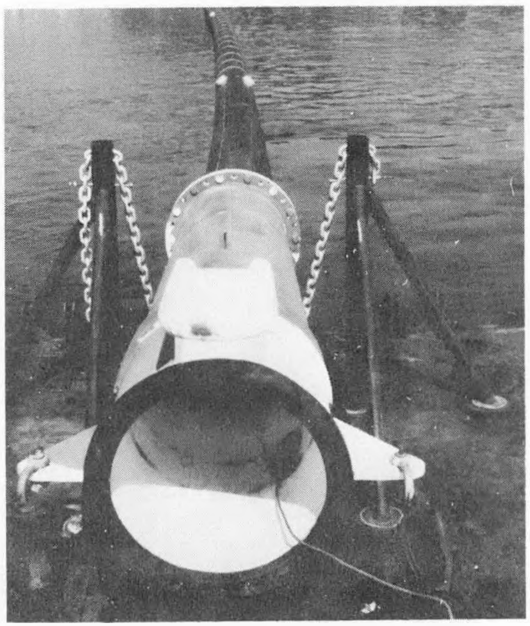
COMPLETED BODY AND SUBSTRATE READY FOR DEPLOYMENT



FABRICATION OF UPWELLING PIPE "STRING"

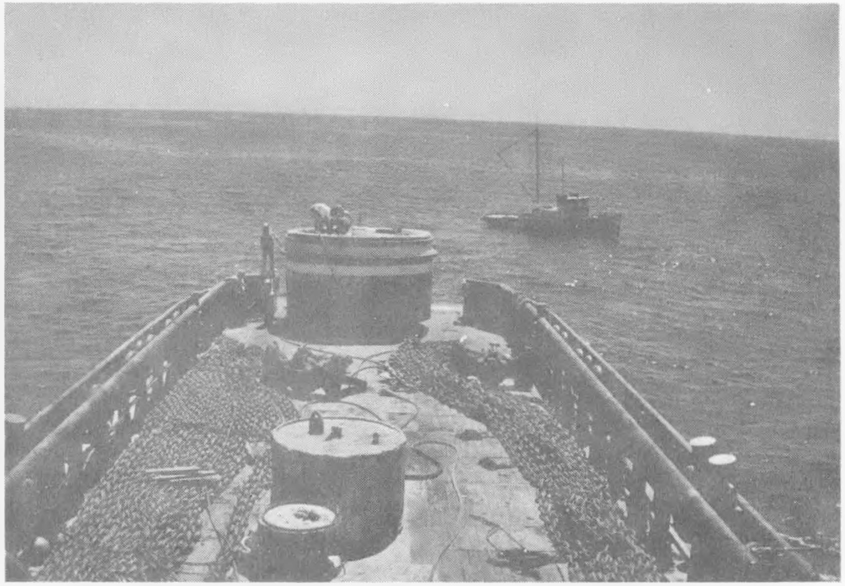


WELDING OF PIPE SECTIONS

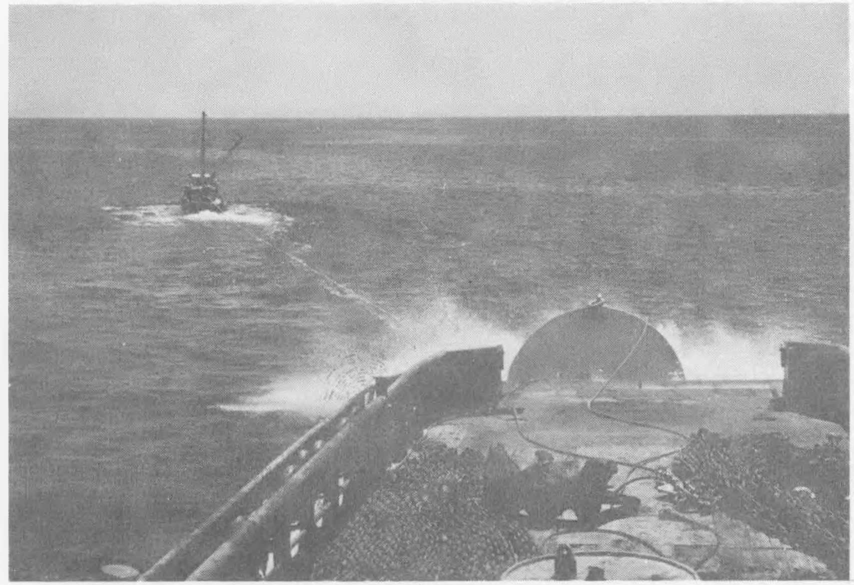


FOOTPIECE OF PIPE ASSEMBLY

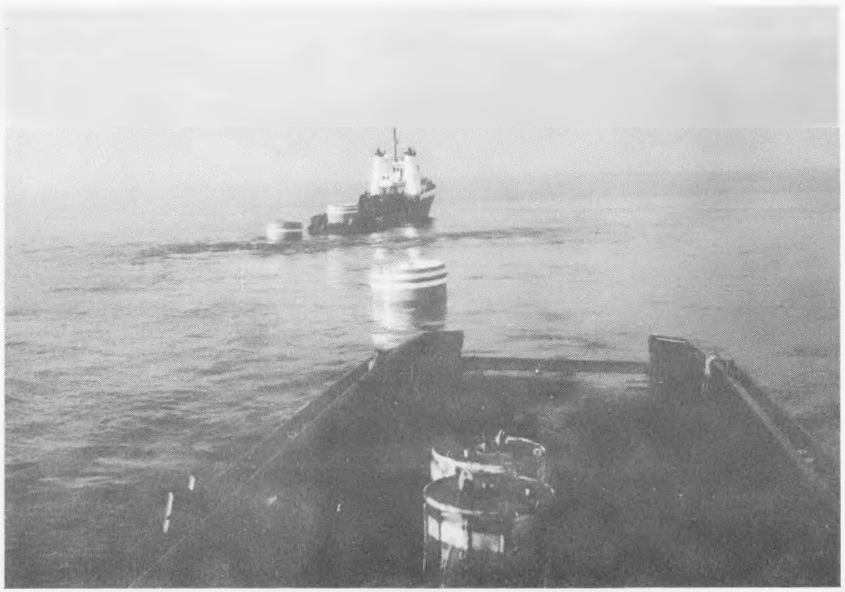
COMPLETED PIPE STRING READY FOR DEPLOYMENT



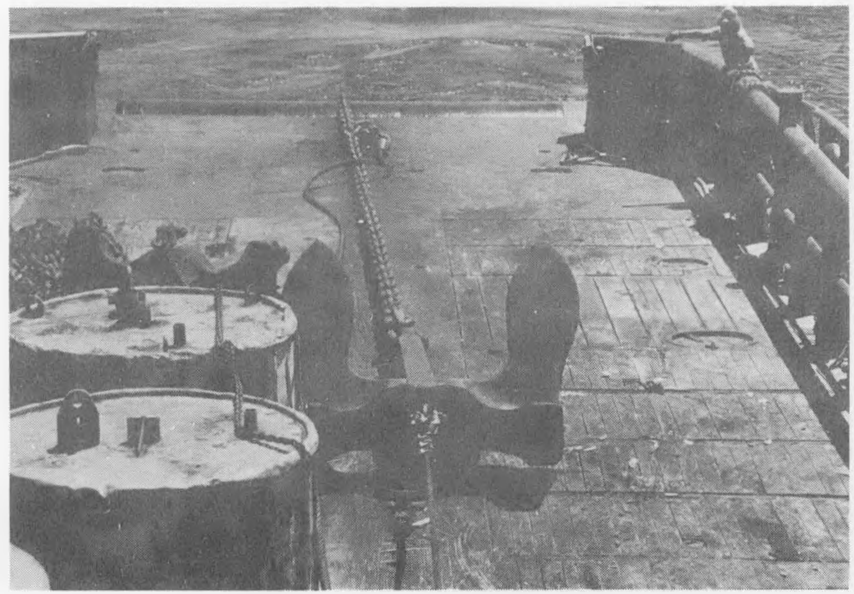
WORKBOAT WITH MOORING BUOY AND ANCHOR HANDLING BOAT



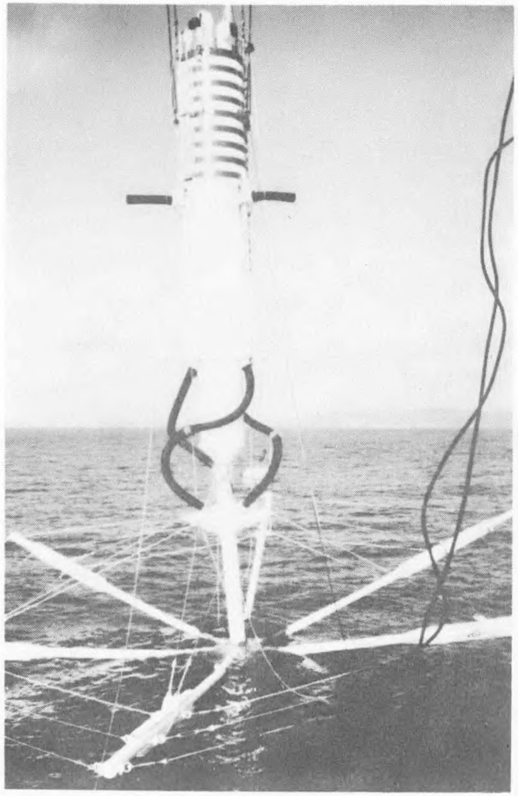
DEPLOYMENT OF A MOORING BUOY

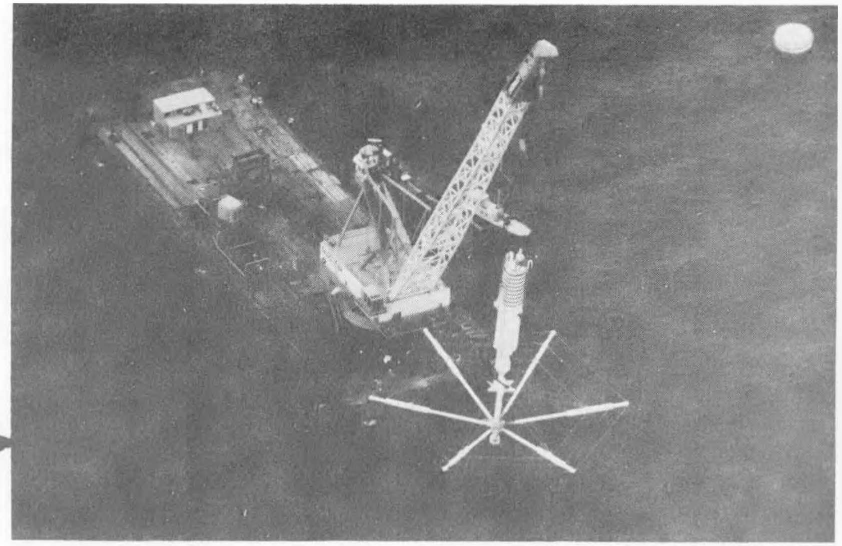


MOORING BUOYS DEPLOYED

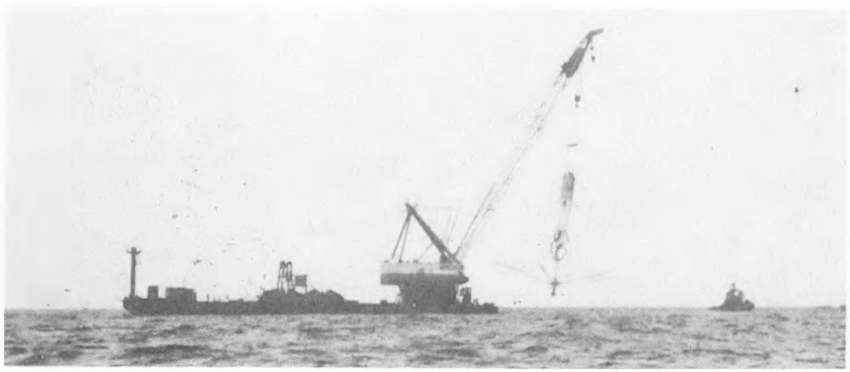


ANCHOR DEPLOYMENT

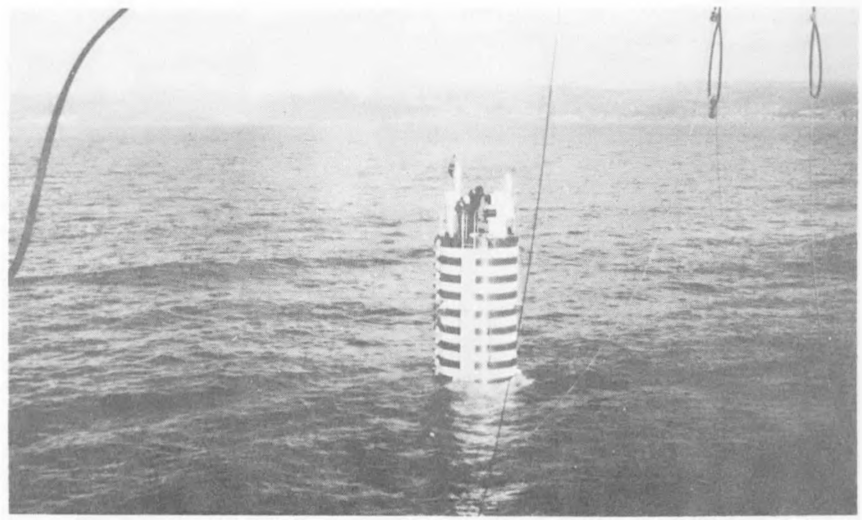




BUOY AND SUBSTRATE AT FARM SITE READY FOR DEPLOYMENT



LOWERING OF BUOY SUBSTRATE INTO WATER



BUOY AND SUBSTRATE FULLY DEPLOYED