11-9-1967

Proposal NTC 67-19 to the State of Maine Department of Sea and Shore Fisheries : Engineering Design of a Controlled Temperature Under-sea Lobster Farm

Nuclear Technology Corporation

PROPOSAL NTC 67-19

TO

STATE OF MAINE
DEPARTMENT OF SEA AND SHORE FISHERIES

ENGINEERING DESIGN OF A CONTROLLED TEMPERATURE UNDER-SEA LOBSTER FARM

NOVEMBER 9, 1967

**NUCLEAR
TECHNOLOGY
CORPORATION**
116 MAIN STREET, WHITE PLAINS, NEW Y

STATE OF MAINE

DEPARTMENT OF SEA AND SHORE FISHERIES

MEMORANDUM

Date November 14, 1967

To Phil Goggins

From Robert L. Dow RLD

Subject Proposal from Nuclear Technology Corporation

The attached letter and proposal, I believe, are self-explanatory. This is an acquaintance of Brad Sterl's who was interested in our work at Cousins Island, and he has outlined this proposed study by his company. I do not believe that it differs substantially from TRW's $25,000 proposal.

I would like to have you and Jim, or anyone else who is interested, look it over and let me know what you think of it.

NUCLEAR TECHNOLOGY CORPORATION
116 MAIN STREET
WHITE PLAINS, NEW YORK 10601

914 WH 9-5660

November 9, 1967

Mr. Robert L. Dow
Department of Sea and Shore Fisheries
State House
Augusta, Maine 04330

Reference: Proposal NTC-67-19 "Engineering Design of a Controlled Temperature Under-Sea Lobster Farm"

Dear Mr. Dow:

I enjoyed the opportunity of meeting with you to discuss your plans for a controlled temperature lobster farm in the cove on Cousins Island. Since our meeting, Nuclear Technology Corporation has studied the problems associated with design and construction of an aquaculture environment. We are convinced of the feasibility of such a venture, and would be anxious to provide the necessary engineering support.

Therefore, Nuclear Technology Corporation is pleased to submit the enclosed proposal to develop an engineering design of a controlled temperature under-sea lobster farm. We estimate the work would require six months to complete, and would cost approximately $25,000. If our proposal meets with your approval, we would be happy to discuss the type of contract which would be the most practical for the Department of Sea and Shore Fisheries.

We would also be happy to discuss any aspects of the program with you in more detail at your convenience.

Very truly yours,

NUCLEAR TECHNOLOGY CORPORATION

Anthony Stathoplos
Vice President

AS:ab
Encl.

NUCLEAR TECHNOLOGY CORPORATION

PROPOSAL NTC 67-19

TO

STATE OF MAINE
DEPARTMENT OF SEA AND SHORE FISHERIES

ENGINEERING DESIGN OF A CONTROLLED TEMPERATURE UNDER-SEA LOBSTER FARM

NOVEMBER 9, 1967

TABLE OF CONTENTS

1. INTRODUCTION

Nuclear Technology Corporation proposes to perform evaluation and design studies in connection with a controlled temperature aquaculture environment for the Maine Department of Sea and Shore Fisheries. This controlled environment is to be directed mainly toward lobster farming at Cousins Island, Yarmouth, in Casco Bay. The program proposed here would have as its end objective the conversion of what is essentially a thermal pollution discharge from a power plant to the practical use of sea farming.

The immediate goal of the proposed program is to prepare the conceptual design of a system of controlled temperature areas in Cousins Cove, and to provide a cost estimate of the detailed design, fabrication, and installation of the system.

The approach of this program will be to apply current engineering technology to achieve a low cost, high performance, maximum reliability system design which will meet the range of marine biological requirements, take maximum advantage of the natural environment of the cove, and make full use of the heated seawater discharge from the Central Maine Power Company plant.

Design of the controlled environment involves the principles and practices of three disciplines. These are heat transfer and fluid flow, materials engineering, and oceanography. A discussion of several pertinent aspects of the technology involved in these areas is presented in Section 2 of this proposal.

Evaluation of the technical problems and fulfillment of the goals of this program will be accomplished in four separate tasks. The influences of heat transfer and fluid mixing on system design will be evaluated in Task 1. The influences of the physical environment on system design and location will be evaluated in Task 2. Conceptual design, including selection of proper materials of construction, will be performed in Task 3. A cost estimate for designing, fabricating, and installing the recommended system will be prepared in Task 4. More detailed discussion of work scope in each of these Tasks is contained in Section 3, herein.

It is proposed to complete this program within a six month period. The schedule for executing the various tasks is presented in Section 4.

Nuclear Technology will assign senior members of its staff to this project to insure that maximum use is made of the company's background and experience. The experience of key personnel who will participate in this program is described in Section 5.

2. TECHNICAL DISCUSSION

The design of a controlled temperature underwater environment for lobster farming involves the understanding and application of principles in three areas of technology -- heat transfer and fluid flow, materials engineering, and oceonography. A discussion of considerations pertinent to the design in each of these areas follows.

Heat Transfer and Fluid Flow

The controlled environment system can be considered in two parts -- one is the distribution subsystem which allocates the required heating water to each controlled area, and the second is the subsystem of individual areas. These individual areas could range in size from a minimum of perhaps a tenth of an acre to a maximum size encompassing the entire cove. It is probable that in the early stages of this program, an objective directed toward achieving small controlled temperature areas is the more feasible approach.

Associated with the water distribution system are specific heat transfer and fluid flow problems. For example, the question of pumping requirements and flow allocation within the distribution system is influenced by factors such as heat requirements of each controlled area, fouling and deposition within the pipes, and temperature fluctuations in the plant effluent. A network momentum analysis can be performed to insure that adequate flow and heat are supplied to each controlled area over the entire range of expected operating and environmental conditions, and to predict the associated pumping power requirements. The question of heat losses from the distribution subsystem piping to the ocean will be considered using existing correlations for natural convection heat transfer from external pipe surfaces.(1) Where pipes are lying on the cove bottom, estimates of heat losses using two dimensional conduction models can be obtained.(2)

The heat transfer and fluid flow problems associated with individual controlled areas involve also questions of heat loss by convection to the ocean and conduction to the ground, as well as questions of temperature and flow distribution due to natural and forced convection within enclosed and open spaces. Established methods of analyzing situations of this nature are described by Bird, et al, (3) Knudsen and Katz, (4) and Batchelor (5). These methods will be used to predict flow requirements, and to design individual distribution systems within each controlled area.

In order to minimize the temperature fluctuations and flow requirements in the controlled areas, it will be necessary to take advantage of the natural terrain and tidal currents in the cove. The influence of ebb and flood tidal flow on the natural convection and mixing occurring in and around each controlled area will be evaluated. Linear superposition methods conventionally used in analyzing transport phenomena will be used to predict these effects.

As an example of scoping calculations which can be readily made, consider the problem of heating the entire cove with the power plant effluent. An analytical model to represent the entire cove can be formulated. The water volume contained in the cove is assumed to vary between 97 and 194 million gallons during a 24 hour, 50 minute tidal cycle. The inventory and volumetric rate of change can be represented in this model by the following analytical expressions:

$$V = 97 + 48.5 \quad \{1 + \cos (2\pi\theta)\}, \quad 10^6 \text{ gal.} \qquad (1)$$

$$\dot{V} = - 205{,}000 \sin \quad (2\pi\theta), \quad \text{gpm} \qquad (2)$$

where-

V = volume of water in cove, gal.

$\dot{V}$ = rate of change of cove volume, gpm

θ = fraction of a 24 hour, 50 min. cycle

Equations (1) and (2) are graphically depicted in Figure 2.1.

To establish upper limits on the heating capabilities of the plant effluent, it can be assumed that both ocean water brought in by the tide and the power plant effluent mix perfectly with the contents of the cove.

Within the framework of this model, two different mechanisms for adding water to the cove during a rising tide can be assumed. These are:

1. Ocean water, at its ambient temperature, is assumed to flow into the cove due to a flood tide at a rate equal to the rate of change of the cove volume (Eq. (2)). At the same time, the plant effluent is assumed to displace its equivalent of cove water, at the cove temperature, into the ocean.

2. The plant effluent is assumed to be completely retained within the cove. The difference between the rate of change of cove volume and plant effluent rate is supplied by the ocean at its ambient temperature.

Both of the above mechanisms have been evaluated to establish upper and lower bounds on the feasible cove temperature levels.

Mechanisms for heat transfer between the cove and the environment, other than by tidal transport, have been identified and their magnitudes estimated. These mechanisms are listed in Table 2.1. Their magnitude can be compared to the total heat transport of the power plant effluent, which is 573 MW_{th}.

In order to maintain a constant temperature in the cove over the entire tidal cycle, it is necessary that the heat addition of the plant effluent just compensate for all other mechanisms of heat loss. For both of the mechanisms of water addition described previously, the peak demand for power plant effluent occurs at the time the tide is coming in and the cove water level is midway between high and low tide. Taking the peak plant effluent rate at 130,000 gpm, the maximum temperature difference which can be sustained between the cove and the ambient ocean has been computed for each of the two assumed mechanisms as a function of other heat losses. This result is presented in Figure 2.2. It is shown that, in the limit, the largest temperature differential between cove and ocean temperature which could be maintained is $19^{\circ}F$. For the more pessimistic model investigated, the upper limit is about $12^{\circ}F$.

For the case of zero heat losses and maximum attainable temperature differential (either $19^{\circ}F$ by mechanism 1 or $12^{\circ}F$ by mechanism 2) the effluent flow schedule required is illustrated in Figure 2.3. It is noted that for the entire period that the tide is ebbing, no flow is required, and that peak flow is demanded halfway in time between high and low tide.

Similar calculations can be made for individual smaller controlled temperature areas within the cove.

Materials Engineering

Two important criteria will dictate the choice of materials to be used in the controlled environment system -- cost and compatibility. Different materials of construction may be required for the two functionally different distribution and controlled area subsystems. The distribution system will consist of sections of piping, with fittings, which carry the heated seawater to the controlled areas. Both the interior and exterior of the pipes will be exposed to the seawater environment. It will be necessary for the piping to resist wasting, crevice and stress corrosion, excessive pitting, and biofouling. If more than one material is used in construction, galvanic corrosion must be avoided. Metallic materials which are candidates for the distribution subsystems include carbon steel, low alloy and stainless steels, brasses, bronzes, Inconel 600, Monel 400, Hastelloy C, and titanium alloys. Nonmetallic materials include rubber products, plastics, bituminous coatings, and antifouling paints for metals. In terms of material cost, the carbon and low alloy steels are most desirable. It is possible, however, that ease of installation might favor nonmetallics for piping. The extensive experience which has been accrued by the marine industries and oceanographic research will be used to select the most economical materials which will do the job. It is also important that the selected material(s) do not significantly affect the bio-environment. The presence of dissolved copper, for example, is known to be harmful to many forms of marine life. It is expected that the marine biologists of the Main Department of Sea and Shore Fisheries will participate in the selection of final system materials to assure that no harmful biological elements are introduced.

The controlled areas in which the lobsters will be farmed may be partially or completely enclosed on the bottom, sides, and top. The choice of enclosure materials will be dictated also by both compatibility and cost considerations. Here, however, the size and shape of the enclosures may eliminate certain materials due to fabrication, installation, and handling problems. It would appear that enclosure requirements may be more easily provided by rubber or plastic components, rather than by metallic rigid forms. Careful consideration of all aspects of the materials engineering problems will be required to arrive at an economically optimum design.

Oceanography

In order to design a minimum cost, maximum performance aquaculture environment in Cousins Cove, it will be necessary to understand and take maximum advantage of the natural terrain and tidal currents in the cove. It is possible that larger circulation and exchange with the bay waters, or adverse subsurface currents will favor one location in the cove relative to another. It is also possible that location of several controlled areas in a particular pattern will take best advantage of the thermal gradients and lead to maximum performance. For these reasons, existing current survey data will be evaluated in terms of design objectives. If necessary, consideration will be given to making additional measurements in the cove. Relatively inexpensive, compact, and simple devices such as the Ekman current meter, the electrodeless in-situ salinometer, and the fisheries type reversing thermometer could be used to measure current, temperature, and even salinity. The type and extent of measurements would be dictated by the importance and influence the data may have on the design. If such information is critical, a more sophisticated method of investigating tidal current transport and mixing could be performed using the Rhodamine-B dye tracer method with an in-situ fluorometer.

TABLE 2.1

Mechanisms of Environmental Heat Exchange

Heat Addition:	
Sun load - (avg. over 24 hr. day)(6)	
Winter solstice	14 MW_{th}
Equinox	38 MW_{th}
Summer solstice	59 MW_{th}
Heat Losses:	
Radiation (night)	41 MW_{th}
Ground conduction	1.3 MW_{th}
Surface convection & evaporation	25 MW_{th}

FIGURE 2.1

TIDAL INFLUENCES ON COVE INVENTORY

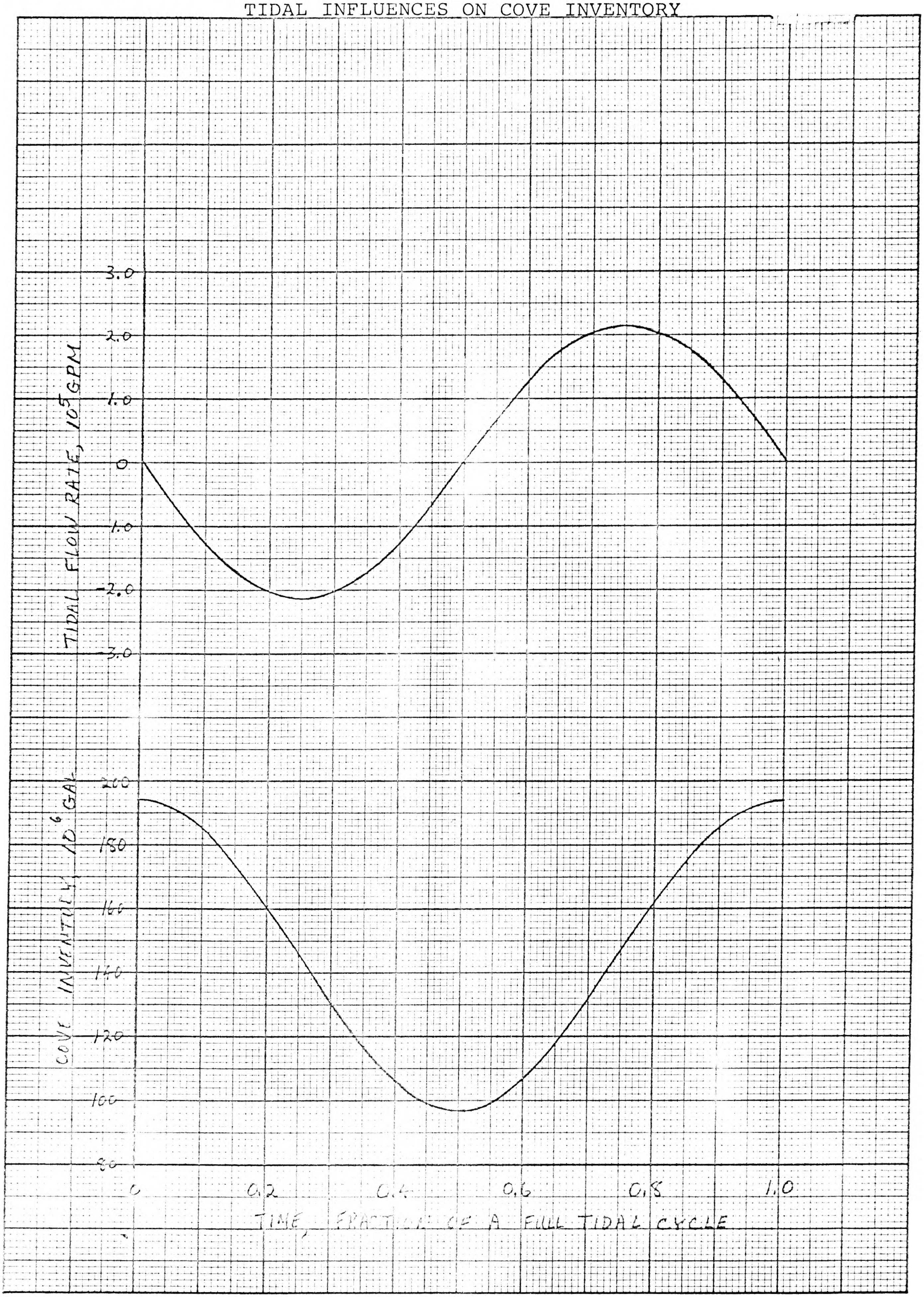


FIGURE 2.2

MAXIMUM ATTAINABLE CONSTANT TEMPERATURE DIFFERENTIAL BETWEEN THE COVE AND THE AMBIENT OCEAN

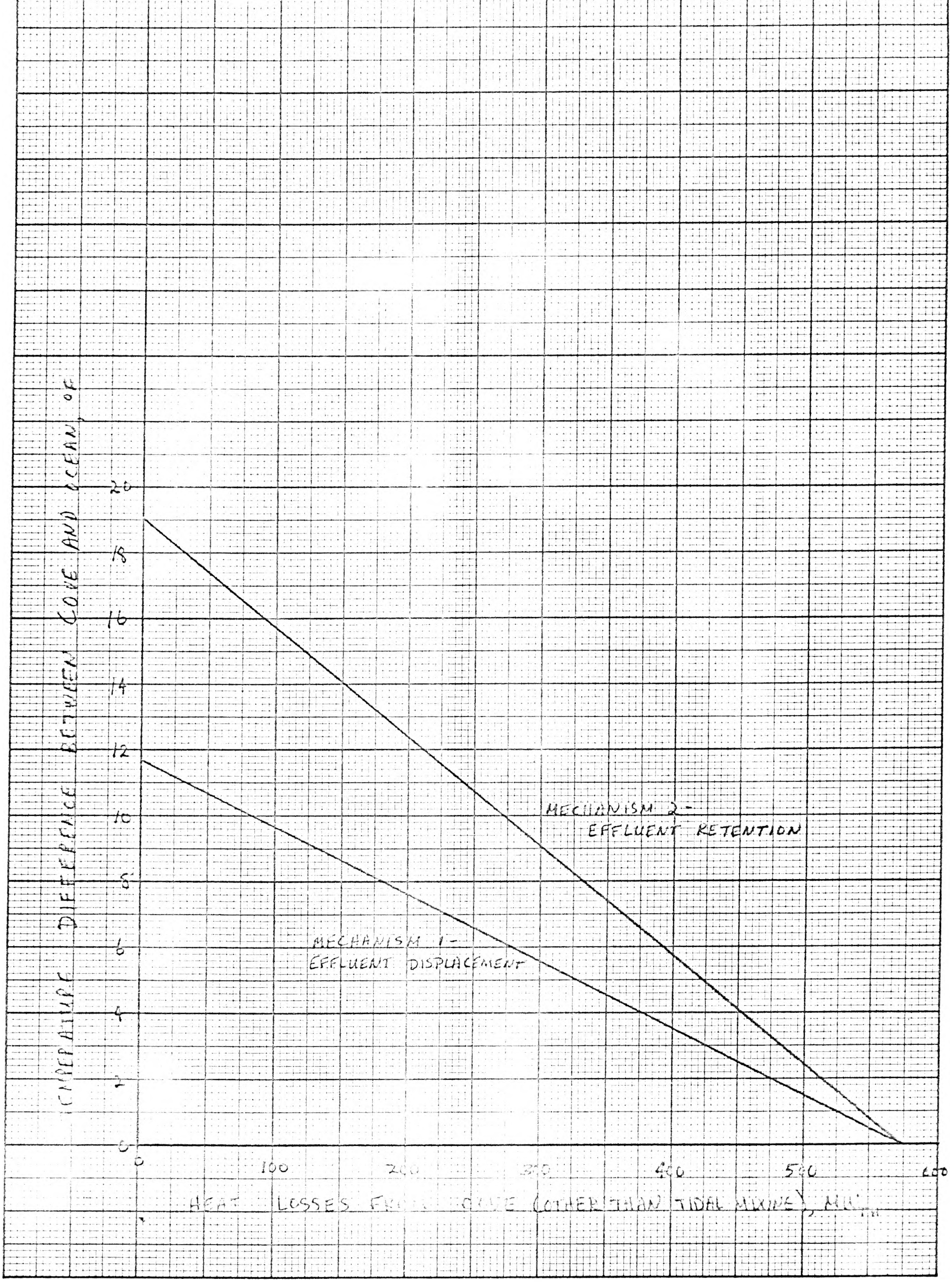
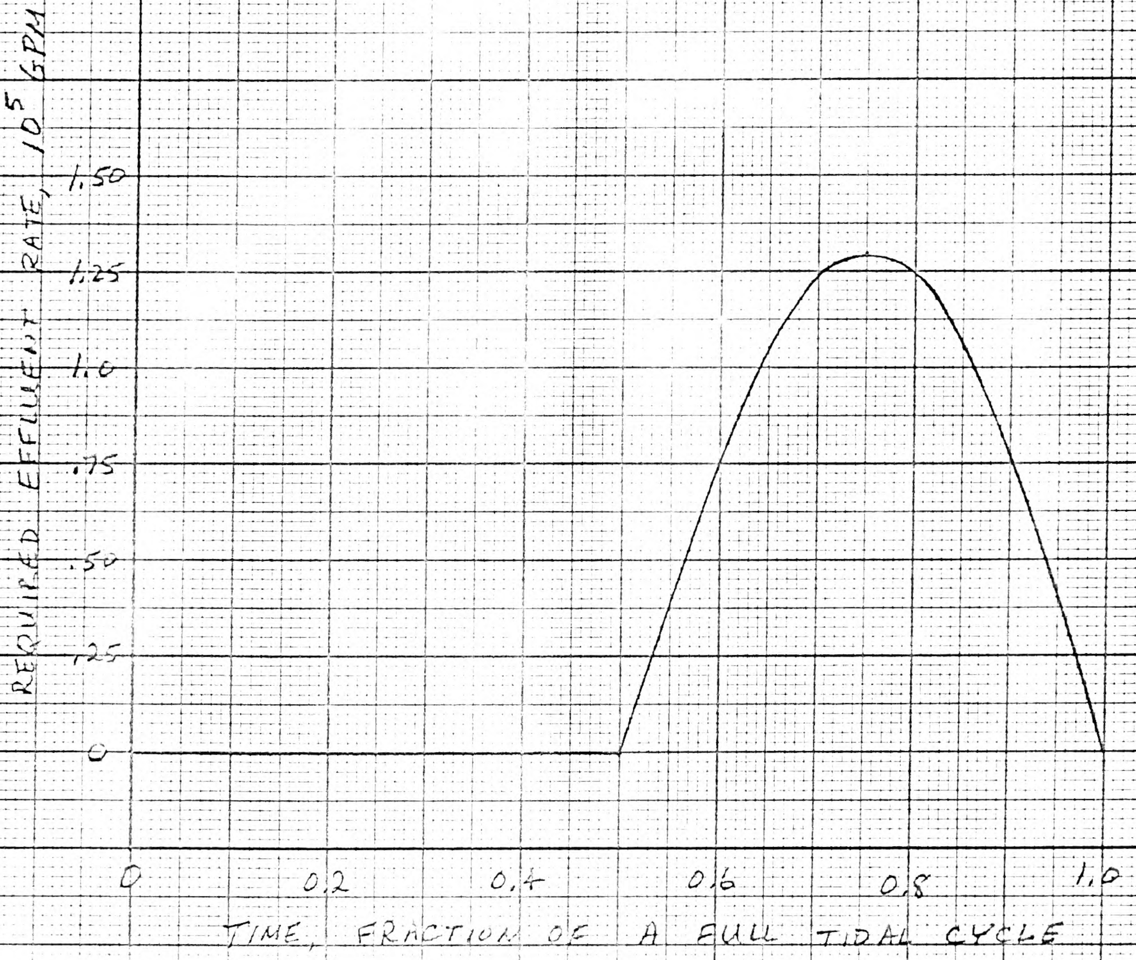


FIGURE 2.3

PLANT EFFLUENT FLOW REQUIREMENTS TO
MAINTAIN A CONSTANT TEMPERATURE
DIFFERENTIAL BETWEEN COVE AND OCEAN



References

(1) W.H. McAdams, "Heat Transmission", McGraw-Hill Publishing (1950)

(2) Carslow & Jaeger, "Conduction of Heat in Solids", Oxford University Press (1959)

(3) Bird, Stewart, and Lightfoot, "Transport Phenomena" John Wiley & Sons (1960)

(4) Knudsen and Katz, "Fluid Dynamics and Heat Transfer"

(5) G.K. Batchelor, "Heat Convection and Buoyancy Effects in Fluids", Quarterly Journal of the Royal Meteorological Society, 80, p. 339 (1954)

(6) Mechanical Engineer Handbook, 6th Ed, T. Baumeister-Ed. Section 12.

3. WORK SCOPE

The scope of activities which comprise the proposed program of designing a controlled temperature underwater environment for lobster farming in Cousins Cove is divided into four technical tasks and one administrative task. The objectives, approach, output, and level of effort assigned to each of the tasks is discussed below.

Task 1 - Methods of Controlling Temperatures

Objectives: To conceive and evaluate alternate methods of achieving a uniform temperature environment in partially or completely enclosed underwater areas.

Approach: Various combinations of enclosure arrangements and internal (and/or external) heated-water distribution arrangements will be analyzed. The arrangements will be evaluated with respect to the following criteria:

1. Uniformity of temperature
2. Degree of mixing
3. Heated-water temperature and flow requirements
4. Heat losses to surroundings
5. Susceptibility to changes in environment
6. Utilization of the external environment

Typical enclosures which will be considered will include bubble domes, cylinders with and without roofs, enclosures with and without floors and entry points. Heated-water distribution arrangements will include sub-floor, floor, and above floor perforated pipe with and without baffling, and external natural convection "thermal curtains."

Results: A quantitative evaluation of the various controlled environment arrangements will be presented. One arrangement will be recommended as a reference system for further design and evaluation.

Level of Effort: 20% of the total effort.

Task 2 - Interaction and Influences of Natural Environment

Objectives: To evaluate the influences of the terrain and oceanography of Cousins Cove as they relate to the design and location of the controlled-temperature areas.

Approach: Data will be gathered from all available sources describing the terrain and currents in the vicinity of Cousins Cove. Full use will be made of information provided by the U.S. Coast and Geodetic Survey, and the Central Maine Power Company. Using the available data, tidal current flow will be estimated at various points in the Cove. Where data are lacking, and where these data are considered necessary, a program for making field measurements will be developed. Theoretical methods of physical oceanography will be used to extend the available data, when possible.

Results: A quantitative prediction of tidal flow currents as a function of location in the Cove will be presented. Recommendations for preferable location of the controlled-temperature areas from the viewpoint of oceanographic characteristics will be made. The objectives, equipment, procedure and cost of oceanographic measurements will be outlined, if necessary.

Level of Effort: 15% of the total effort.

Task 3 - Conceptual Design of a Reference System

Objectives: To describe, through functional specifications, operating characteristics, and engineering drawings, the conceptual design of a recommended system of controlled-temperature areas, and to select the appropriate materials of construction.

Approach: The results and recommendations of Tasks 1 and 2 regarding the arrangement of individual controlled-temperature areas and their location will be expanded into a practical engineering design from which cost estimates and detailing can be made. Alternate methods of arranging the heated water distribution system from the source to the separate areas will be evaluated, and a reference scheme will be recommended. The various candidate materials for the controlled area and distribution subsystems will be evaluated for the reference concepts, and a design recommendation will be made. Engineering drawings of the entire system will be prepared, and analysis of the performance of the specific reference system will be performed.

Results: A scheme for distributing the heated water to the controlled-temperature areas will be recommended. Materials of construction for the controlled areas and distribution subsystems will be chosen. Engineering drawings and a compilation of operating characteristics for the reference system will be prepared.

Level of Effort: 45% of the total effort

Task 4 - Cost Estimating and Scheduling

Objectives: To estimate the cost and schedule of building and putting into operation the recommended controlled-temperature system.

Approach: Conventional methods of cost estimating, in conjunction with discussions with vendors, will be used to predict the cost of detailing, fabricating, installing, and testing the reference system. A time schedule for the completion of the project will also be prepared. Those areas which may require unconventional materials or methods, or which may require development, will be pointed out.

Results: A cost estimate and time schedule for completing the project will be prepared. Development requirements will be identified.

Level of Effort: 10% of the total effort.

Task 5 - Project Engineering

Objectives: To provide technical direction and supervision to the project, and to maintain liaison and report to the Maine Department of Sea and Shore Fisheries.

Results: Overall technical direction and supervision will be provided. Periodic meetings and progress reports will be made to the Maine Department of Sea and Shore Fisheries. A final report of results will be issued.

Level of Effort: 10% of the total effort

4. SCHEDULE

The proposed program will be completed within six months of receipt of a contract. The schedule for executing the various tasks is presented in Figure 4.1.

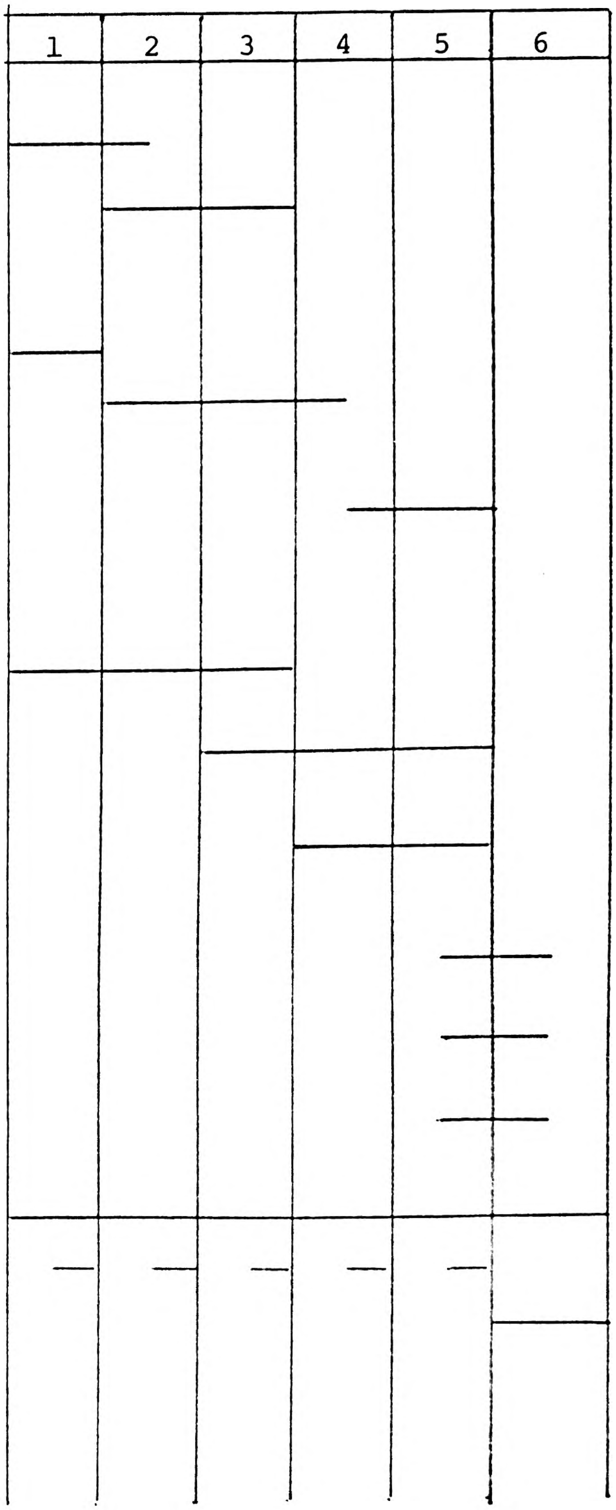
FIGURE 4.1

SCHEDULE FOR ACCOMPLISHMENT OF WORK SCOPE

TASK

1. Methods of Controlling Temperatures
   1.1 Define alternate methods
   1.2 Evaluate alternates and select a reference method
2. Interaction and Influences of Natural Environment
   2.1 Gather oceanographic data
   2.2 Evaluate influences on location and pattern of controlled areas
   2.3 Recommend further measurements program
3. Conceptual Design of Reference System
   3.1 Select materials of construction
   3.2 Prepare conceptual design drawings
   3.3 Establish reference system performance capabilities
4. Cost Estimating and Scheduling
   4.1 Prepare cost estimate to complete project
   4.2 Prepare time schedule to complete project
   4.3 Identify development areas
5. Project Engineering
   5.1 Liaison and Consultation
   5.2 Progress Reports
   5.3 Final Report

MONTHS



5. PERSONNEL

Nuclear Technology Corporation will assign senior members of its staff to this project to insure that maximum use is made of the company's background and experience. The personnel who will participate in this program are listed in Figure 5.1 on a project organization chart.

Mr. Anthony Stathoplos, Vice President in charge of engineering, will maintain overall cognizance of the project, and will participate in the technical execution where required. Mr. Stathoplos received B.S. and M.S. degrees in Chemical Engineering from M.I.T. in 1951 and 1952. His experience as project engineer, technical supervisor, and manager of engineering dates back to 1953, when he joined United Nuclear Corporation. He participated in many programs involving thermal, hydraulic and mechanical design of engineering systems. He was instrumental, in many cases, in developing a heat transfer system from its initial conception to construction, installation, and operation. In 1965, Mr. Stathoplos joined Nuclear Technology Corporation. Since then he has directed all engineering activities of the company, as he would do in the proposed project.

Dr. Arthur Goldman will perform as project engineer in the proposed program. He will devote essentially full-time to the management and execution of the project. Dr. Goldman received his Bachelor's degree in Chemical Engineering from the City College of New York in 1957, and his Master's and Doctor's degrees in Chemical Engineering from New York University in 1961 and 1966. He had been with United Nuclear Corporation from 1957 to 1966, and joined Nuclear Technology Corporation in 1966. In addition to his full-time duties as Chief Engineer with Nuclear Technology Corporation, he is an Adjunct Associate Professor of Chemical Engineering at New York University, where he teaches a graduate course in heat, mass, and momentum transfer. Dr. Goldman has had extensive experience in areas related to this project. He has participated in applied research programs involving transient heat transfer, low Reynolds number fluid dynamics, and pipeline network simulation. He has published seven papers and reports in these areas. Dr. Goldman's industrial experience with the analysis and design of sophisticated heat transfer systems has been extensive. He has been responsible for numerous conceptual designs of such systems in a variety of applications. He has also been involved in a number of engineering programs as project engineer, managing efforts which ranged in scope from research and development to design and construction. His background and experience will be applied in full measure to the management and execution of the proposed program.

Mr. Rudolph Hollman is a consultant to Nuclear Technology Corporation on matters relating to oceanography. He will provide qualified judgement and evaluation of the questions related to the influence of the ocean environment on the design and location of the aquaculture system. Mr. Hollman is an Associate Research Scientist in the Department of Meteorology and Oceanography at New York University. He has a great deal of practical experience in physical oceanography by virtue of his position as coordinator and manager of the research vessel KYMA. He has also been involved in many analytical projects pertinent to this one. He has studied, and authored papers on, the solar heating of the sea. He has analyzed and measured subsurface diffusion processes and thermal pollution in large and small bodies of water, including Long Island Sound, New York Bay, the Hudson River, and the Atlantic Gulf Stream and Equatorial Undercurrent. Mr. Hollman has co-authored articles on ocean tides with Professor Pierson of New York University. Mr. Hollman will provide substantial support to this project on problems related to oceanography.

Engineering analysis support for this project will be provided by Dr. John Herbst, Mr. Charles Beattie, and Mr. Jaropolk Kalyna. Dr. Herbst has been with Nuclear Technology since 1965, when he received his Ph.D. degree from New York University in nuclear engineering. He has been involved in a wide variety of engineering projects at Nuclear Technology, which include analysis and design of nuclear reactor cores, heat removal systems, and specialized system components. He will contribute substantially to this project in analyzing thermal diffusional processes.

Mr. Beattie received his Bachelor's and Master's degrees in chemical engineering from the University of Louisville in 1962 and 1963. He expects to receive his Ph.D. degree in 1968 in nuclear engineering. Prior to joining Nuclear Technology Corporation in 1967, he taught a variety of engineering courses at Temple University, including heat transfer and fluid flow, automatic process control, and physical chemistry. His contribution on this project will encompass all phases of analysis.

Mr. Kalyna received his Bachelor's and Master's degrees in nuclear engineering from Columbia University in 1964 and 1965. He expects to receive his Ph.D. degree in 1968 in nuclear engineering from Columbia. Prior to joining Nuclear Technology in 1967, his experience in engineering analysis was gained through part-time summer employment at Brookhaven National Laboratory and Columbia University. He will be involved in all phases of analysis in this project.

The design engineering capabilities on this project will be provided by Messrs. Jacob Wisnik, Christian Heineken and Robert Orlan. Mr. Wisnik, a graduate mechanical engineer from Tufts University and a licensed Professional Engineer, has over 20 years of experience in engineering systems design. His experience includes machine and equipment design and analysis, design, fabrication, and erection of special treating plants for corrosive fluids, and cost estimating for new product and systems development. Mr. Wisnik will provide senior design responsibility on this project.

Mr. Heineken has 17 years of experience as a draftsman, designer, and mechanical engineer. His experience with the Electric Boat Division of General Dynamics, American Machine and Foundry, and Babcock and Wilcox is pertinent and will be usefully applied on this project. He has been involved with materials engineering problems in marine and conventional applications. He has participated and supervised in all phases of design and installation of engineering equipment and systems.

Mr. Orlan is senior designer with Nuclear Technology Corporation. He has nine years of significant experience in machine and equipment conceptual and detailed designing, cost estimating, and systems evaluation. He will be responsible for developing the engineering drawings of the recommended concept for this project.

Primary responsibility for cost estimating and scheduling will be assumed by Mr. Edward Bernsohn. Mr. Bernsohn received his Bachelor's degree in chemistry from the University of Michigan in 1948. Since then, he has been with the Vitro Corporation of America, Babcock and Wilcox, United Nuclear Corporation, and Nuclear Technology Corporation. His experience includes economic evaluation of chemical processing plants, the evaluation of materials problems associated with a variety of engineering and process systems, and as senior project engineer on a number of engineering projects. His project engineering responsibilities have included technical management, planning, scheduling, cost estimating and budget control, and liaison with vendors and subcontractors. His pertinent and significant experience will be of great use to the project.

FIGURE 5.1

PROJECT ORGANIZATION