A Proposal for a New Application of Thermal Energy from the Sea

by

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Chairman, Departmental Committee on Thesis

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Abstract

The temperature gradients found in all oceans are a source of energy. Experiments have been made in an attempt to harness this energy and convert it to electrical power. At the present time, however, no Sea Thermal Energy plants have been deemed successful, nor economically wise.

A new proposal is made for a Sea Thermal Energy plant at a new location. Solutions to the inherent problems of the plant structure are proposed and the economic soundness of such a project is demonstrated.

Introduction

The population of the world is expanding rapidly, Furthermore, the rate of growth is currently increasing. To accommodate these new masses both food supplies and manufacturing must increase. Civilization is rapidly pushing into the unpopulated regions of the world. These expansions all demand an increase in available energy supplies.

The energy production industry grows with population and manufacturing. As the degree of civilization goes up the energy production industry becomes more concentrated, there are less and less individual energy producers, producing only for their own consumption. Thus energy must be produced on a large scale in large plants.

The energy production industries may be put in two categories: first, fuel distribution industries, and second, electricity producing installations. The two industrial categories are not wholly independent, but serve each other. In this thesis we are concerned only with the electrical energy producing industry,

Currently there are two common means for large scale production of electrical energy, and a third which is getting major consideration. The first method of production is the burning of fossil fuels, the most common being oil, natural gas, and coal. The second method is hydroelectric power. The third is nuclear energy.

With increasing needs for electricity the electric power industry is expanding. Eventually we will deplete our supplies of coal, natural gas, and oil. While new deposits are being found, the expense of obtaining the new supplies will rise as the more easily accessible supplies are used up. Engineering advances make it possible to use poorer grade deposits of fuel, which were once uneconomical, but the expense of power production from fossil fuels will inevitably increase. New hydroelectric plants are being constructed, and old ones are being enlarged for better utilization of the available energy, but here again the expense goes up as water power supplies must be tapped in the more inaccessible areas. Nuclear energy plants are already in use, and billions[1] of dollars in research and practical plant developments are being spent because of the feeling that this is the eventual way we must go to produce the energy required by a demanding and increasing population.

There is much feeling that the currently used energy sources will eventually be gone, and we must look for other sources. There are many sources of energy around us. Some of these are hydrogen fusion, tidal power, solar power, thermal power from the seas, and power from the winds.

Most of these new sources of power are not economically competitive with conventional methods for large scale energy production. To apply a new source we must have:

1. The environmental conditions required by this new method.

2. Advantages over the other electrical energy producing methods.

The environmental conditions are obvious, i.e., for solar power we need abundant and predictable sunshine. The advantages can be of many sorts - smaller, lighter, cheaper, more enduring, needs less maintenance, etc., depending on what factor is most important in the particular location where power is needed.

This thesis deals with one of these new energy sources, "thermal energy from the sea". The purpose is to propose and prove that the process of using the thermal energy of the sea should be considered for application now. Thermal power from the sea should no longer be thought of as a novelty. On a price consideration it can be competitive with nuclear energy.

Basic Theory

If we have two bodies, A and B with different temperatures T_A AND T_B respectively, with T_A greater than T_B we know that there can be a flow of heat from A to B. If we insert some form of heat engine between these two bodies we can transform some of this heat flow into useful work.

The amount of heat that flows from the hot to the cold body, and consequently the amount of work obtained is dependent upon the temperature difference between T_A and T_B and the heat storage capacity of A and B. That is to say that the same amount of work could be obtained from two low capacity heat bodies at a high temperature difference as from two large heat capacity bodies at a low temperature difference.

A dimensionless ratio commonly used for heat engines is called the Carnot efficiency. This is $e = \frac{T_A - T_B}{T_A}$ where the T's are used in the absolute temperature scale. This is the ratio of the work energy that can be converted to the total heat energy. We can see that the greater the temperature difference and the closer T_B is to absolute zero the higher is the Carnot efficiency. However, the Carnot efficiency makes no statement concerning the ease with which heat can be transformed into work. It defines only the greatest possible energy which can be transformed into work, using two bodies at temperatures T_A and T_B.

Large temperature differences exist in the oceans. The surface layers are heated by the sun's radiation, but the sun's rays penetrate no farther than 1200 feet deep.[2] The sun's thermal effect on the water is only noticeable within a few feet of the surface. Generally speaking, in all areas of the oceans where the depth is greater than the mixing layer thickness, there is a temperature gradient.

The idea first proposed by Professor D'Arsonval, and perfected by George Claude and P. Boucherot,[3] was to use the ocean's surface water as the hot body and the deep cold water as the cold body. The two bodies should be bridged by some sort of heat engine so that work could be obtained. The Carnot efficiency for such a system would not be high. For example, if the surface water is at 80 degrees Fahrenheit = 540° Rankine, and the cold water is at $40^{\circ}F = 500^{\circ}R$, the Carnot efficiency is $\frac{540-500}{540} = 7.4\%$. The temperature difference is small compared to conventional work producing systems, but the immense and practically unlimited size of these bodies makes the possibilities look worthwhile.

The next problem is what kind of heat engine can be used to turn this available energy into actual work and electrical energy. The conventional steam turbine electric generator plants come to mind. It is interesting to note that for more than 150 years the steam cycle was used for pumping water and industrial power, and for locomotives at efficiencies of from 2 to 6%, and these were considered quite practical and economically sound until a relatively short time ago.

In the ordinary steam power plant water is heated to boiling temperature. The steam is then sometimes superheated. It is then expanded through a turbine where it produces work, and is finally rejected through a steam condenser. The heat transferred to the condenser is rejected to the cold body, usually in the form of available river water at perhaps 90F. The condensed steam is either mixed with the condensing water in the case of a mixing type of condenser, or pumped back into the boiler to start the cycle over again in the case of a surface type condenser.

In the usual steam power plant fuel is burned as the heat source to boil the water. For a sea thermal energy (S.T.E.) plant warm surface water becomes the hot temperature source. At the very maximum the surface temperature may reach 100F at times. This will not boil at atmospheric pressure, since the boiling temperature at atmospheric pressure is 212F. It would appear that some other working fluid should be used!

Claude however had other ideas.[4] He said that the sea water should be used as the working fluid. The warm surface water is brought into the system. The pressure is pulled below atmospheric pressure with a vacuum pump far enough so that the water boils at the available temperature of the warm surface water. The steam is then expanded through a turbine to a condenser where the pressure is still lower than the boiler. The pressure in the condenser is the saturation pressure of the steam at the temperature of the deep cold water. The steam condenses.

Claude pointed out that in addition to producing power from the rotating turbine, all the steam after condensing is pure, fresh water. This water as well as the electricity generated could be sold.

History

In about 1900 Professor D'Arsonval expressed the possibility of using the temperature gradients in the sea as a source of energy. It wasn't until 1926 that George Claude and P. Boucherot demonstrated the feasibility of this idea in a plant at Ougree, Belgium. This plant produced about 60KW gross power and 40KW after subtracting the power for the auxilliary pumps and extractors.[5] This was an experiment void of the difficulties of a long cold water pipe since water from the river Meuse at 66°F was used.while the warm water was the discharge from the Ougree-Maribaye Steel Company. Steam was produced at 94.6°F.

Claude then proceeded to build a plant in Matanzas, Cuba starting in 1929. Here he used the same 60KW turbine but planned to make a complete test of using the sea as the only source of power. The main problem was to build and submerge successfully a large cold water pipe to about 600 meters. After 2 failures on attempts to lay this pipe on the sea bottom, a third attempt was partially successful. The plant operated for eleven days on a reduced scale due to a leak in the cold water pipe.[6]

Claude experimented shortly with a floating plant from a cargo ship "Tunisie". Here again he had trouble with the cold water pipe. The wave action broke the pipe.[7]

In 1941 the study was again taken up by the French under the joint initiative of the Ministere de la France d'Outremer and of the Centre National de la Recherche Scientifique.[8] A site for a possible application of a Sea Thermal Energy (S.T.E.) plant was seen to be at Abidjan, the Ivory Coast. In 1948 the studies led to the formulation of the company "Energie des Mers". This company was to undertake studies for a power station at Abidjan.

Some of the problems and questions of a S. T. E. plant were put under study. Professor Leon Nisolle at the Ecole Centrale des Arts et Manufacturers, studied the evaporation under vacuum at low temperatures and the hydrodynamics of drawing water from the deep cold water region. Andre Nizery worked on the mechanics of building a cold water pipe and the methods of placing it on the ocean bottom. After successful shallow water tests at Brest, France in 1947 operations were moved to Abidjan for trials of laying a pipe in 300 meters of water. Finally in 1956 the tests were completed and successful.

Nizery used special antiwave floating devices which limited the vertical and horizontal reaction on the pipe due to the wave action. The pipe was carried out into the water horizontally and lowered evenly with a minimum of bending using special floating crane platforms which employed the antiwave design. The pipe also was made with some flexibility due to rubber jointing between some sections. Nizery also demonstrated how divers could be used to connect and disconnect the pipe below the surface.

The construction of an S. T. E. plant was stopped however at Abidjan when it was decided the existing hydroelectric apparatus could handle the demand for electricity. A new possible site for applications was needed.

Guadaloupe was picked and the Abidjan study was applied.[9] A plant of 3500KW net power was proposed. Including the sale of fresh water, the cost per KWHR was estimated to be the same as that for a fossil fuel burning plant. If the fresh water would not be sold the cost per KWHR would be twice that of a conventional plant. However, the big drawback was felt to be the lack of engineering experience with all the S. T. E. plant problems, especially the long cold water conduit. Thus, as of 1962, the plant was not built,[10] and no S. T. E. plants are in operation today.

Selecting a Site

The first and most important thing to look for in selecting a site is the temperature gradient.

Temperature profiles of the North and South Atlantic were examined. Those areas where a 15° to 20° Centigrade temperature gradient occurred within 1000 meters of the surface were noted. This was a rather arbitrary limit, however it limited the regions to coastal areas. In general, the isotherms curve upward as they approach the continents. They follow the bottom topographic contours very roughly. Then at many places cold water is available relatively close to shore.

At first glance, it seems obvious that the tropical countries are ideally suited and indeed they are. However, the tropics are not a geographical limitation. There are other possible locations.

The Straits of Florida was found to be one of these locations where a severe temperature gradient exists. The Gulf Stream is funneled northward between the Florida Keys, East Coast of Florida and the Bahama Banks. The Gulf Stream is noted for its volume flow of warm water.

The temperature across the Stream varies from 29°C at the surface to 5°C at the bottom in many places. (See Fig 1) The average seasonal surface temperatures were examined.[11] In the winter the surface temperature drops but, the average minimum is only 24°C or about 75°F while the bottom; temperature doesn't change with the seasons. (See Fig 2)

There are excellent temperature gradients all along the Gulf Stream due to the flux of warm water northward. It remains for us to pick a spot in the Gulf Stream off the coast of Florida.

Since the temperature gradient question is answered, we must now turn to the next criterion. Florida is a large and growing consumer of electric power. Their manufacturing employment is growing faster than that of the United States.[12] Florida Power and Light reports the total electric sales per year show rapid increases. From 1952 to 1962 the total energy sales per year have increased from 1,916,365,000 kwhr to 8,663,121,000 kwhr. The increase alone from 1961 to 1962 was almost 1 billion kwhr sold. The number of electric customers is increasing. In the same period, 1952 to 1962, the total number of customers has increased from 390,946 to 822,103. The increase from 1961 to 1962 was 41,682.[13] All indicators point to expanding electrical use.

Florida Power and Light Company which takes in most of the Southern half of Florida plus the entire Eastern coast of Florida, produces all of its power by fossil fuels. The fuel costs per kilowatt hour fluctuate over the years but as of 1961 they were at a low. (See Fig 3). The efficiency of the plants is improving such that the costs per kilowatt hour are decreasing, but this trend can't go on indefinitely. The total U. S. electric utility industry shows increasing efficiency. The result is a very slightly decreasing overall cost of fuel per kwhr.[14] Eventually, as oil and coal become more scarce, the fuel cost must rise.

The Miami area is one of the largest consumer areas in Florida. The five electric plants for the Miami area had a gross generating capacity of 1441 MW as of 1961. The growth of this area is seen on the graph. (See Fig 4) Thus the Miami area is a likely spot for needed increased generating capacity. A thermal power plant placed in the Straits of Florida off Miami would be at an ideal location. The temperature gradients are available near a large and growing power consumer market.

After a careful study of the depths and temperature gradients abreast of Miami, the following area is thought to be the most ideal location for a Sea Thermal Energy plant. An area bounded on the north by the latitude 25° 41'N and bounded on the south by 25°31'N, on the west by longitude 79°45'W and on the east by 79°37'W. (See Fig 5) This area is about 33 miles east south-east of Miami and is in the middle of the Florida Current. It may be seen from the profiles that the channel is over 800 meters deep. (See Fig 1)

In locating a plant we must also evaluate whether or not there is sufficient cold water supply, that is, if there is a large enough cold water layer so that no warm water will be pulled down and into the cold water layer. The studies of Nisolle were concerned with this vacuuming of the deep cold water layer. The results of his studies are expressed in the following relationship.

$$E = .68\,(.04)^{.787} \times \left(\frac{q}{H^2\sqrt{H}}\right)^{.212} \times H$$

E is the maximum thickness of the layer of cold water vacuumed from the bottom. H. is the height of a theoretical column of water which has a bottom layer density equal to twice the surface layer density. The column has a density gradient equal to the density gradient of the selected area. q is the flow of cold water. As an example, take the density gradient for the Abidjan location. For a 50,000kw plant using a flow of q equal 80 cubic meters per sec. from a depth of 400 meters, H is equal to 800,000. Then E, the thickness of the vacuumed horizontal layer will be 80 meters. For a 2 meter diameter pipe that is 39 meters above and 39 meters below the pipe opening.[15] Then the thickness of the cold layer would not seem to be a crucial one for the Straits of Florida. 200 meters of water less than 7°C lie in the channel. (See Fig 1)

It is obvious that the variation in surface temperature with the seasons, as shown on Fig 2 will affect the available power output of a plant, since the higher surface temperature will produce an appreciably higher output of power. This, however, is not as great a disadvantage as it might seem. A' glance at the surface temperature graph shows that the temperature is highest and the available power greatest when the weather is also hottest.

Since one of the largest power loads in Florida is the air conditioning load and this is greatest when the weather is hottest, it will match the power capability cycle almost perfactly. This is a fortunate situation, and will make the Sea Thermal Plant fit requirements to capability very well indeed.

The Florida Current provides a means for disgarding the cold condenser water downstream preventing the possibility of cooling our warm water supply. (See Fig 6)

Engineering A Plant

George Claude had his major difficulties with the long cold water pipe. In 1941 after the French had taken up the studies again for application in Abidjan they realized that the major problem blocking the effective application of thermal power from the sea was the submerged pipe problem. This was the reason for the work undertaken by Andre Nizery in Brest.

The problem was to carry a pipe out into the water and lay it on the ocean bottom without having it break or damaged. The vertical and horizontal wave forces and the uneven bottom were the causes of breakage.

Nizery designed flexible rubber sections for the pipe so that it could give and bend when submitted to stresses. He also designed anti-wave floating devices which limited the rise and fall of the floating platform. With 2 meter waves the platform fluctuated only 30 centimeters.[16] The continuation of the work in Abidjan was to see if Nizery's whole conception could be applied successfully to full scale operations in deep water.

The experiments at Abidjan were quite successful and proved that the pipe with flexible connections could be layed along the bottom. This work was all done on the assumption that the plant would be built on shore, and the pipe layed along the bottom. While the French had suggested the possibility of building a floating plant,[17] they seem to have done all their work on shore based on plant designs.

We would propose to build a floating plant, with a suspended, semibuoyant cold water pipe. This has a number of advantages:

1. The pipe will be much shorter and pumping power is directly proportional to L/D ratio of the pipe. For example, the French proposed a shore based plant where depth at intake was 700 meters and the pipe length was 4200 meters, or 6 times the depth.[18] This makes a serious difference in the pumping power loss.

2. By making the plant structure quite deep, say 200 feet or more the pipe is connected at a point well below any wave motion. Note that at 3/4 wave length depth the wave forces have diminished to 1% of their value at the surface.[19]

3. The plant structure can be made extremely stable by making it, deep so that it is almost independent of wave and storm forces. This has already been demonstrated by the ship "Flip" [20] and the plant structure could be built on similar principles.

4. The pipe laying problem can be made very simple, as shown in fig. 7 by dropping the pipe right through the plant structure. This means the pipe would never be subjected to heavy wave forces at this juncture, because the bottom of the structure is almost immovable with repsect to the water.

5. By having the pipe suspended from the structure, it is possible to use one large pipe for several turbines. Since the physical size of the turbine is so large for a given power, this

construction would be advisable, again to keep the cold water pumping power to a minimum. For example, for a 5000 kw plant with a 2 meter diameter pipe: By going to a 4 meter pipe the capacity would go to 20,000kw., and it should easily be possible to use an 8 meter diameter pipe with 80,000 kw capacity.

6. The floating plant requires practically no land investment. Shore land is very expensive in Florida, and with a floating plant, only a cable terminal station, and perhaps a maintenance dock would be required on shore.

7. The floating plant is almost independent of bottom conditions. The French had to search for a steep, but not too irregular bottom for a shore based plant. Since cable laying is a long established science, this should be no great problem, so that the floating plant, could have a location choice dictated almost by water conditions alone.

Since the major problem with the floating plant is the cold water pipe construction and suspension, it becomes important to show how it can be made. The pipe is made of corrugated material so as to make it flexible, as shown in Fig 8. Eternal to the corrugated pipe is a layer of plastic foam or polyurethane[21] the thickness of which is determined as follows.

We want the pipe to hang in as nearly a straight line as possible. This is necessary to prevent exessive bending stresses. A unit length of pipe in the water has 2 forces acting upon it, the drag of the current and the weight of the pipe in the water at its particular depth (varies very gradually with depth). (See Fig 8)

Resolving the 2 forces we get a resultant force. If the buoyancy of the pipe is controlled by varying the volume or density of the wall of the pipe, we can vary the weight of the pipe in the water. Then dependent upon the drag, if we vary the weight we can keep the resultant force always along the axis of the pipe.

We can vary the buoyancy by varying the thickness of the layer of foam plastic. External to the foam is another corrugated pipe. Now we have concentric corrugated pipes sandwiching a variable thickness of foam dependent upon the current drag.

It is not expected that the pipe will hang in a perfectly straight line at a constant angle because the currents fluctuate somewhat. Therefore the corrugated flexibility is built in and is necessary. However, the variable density controlled pipe will much lessen the bending upon the long conduit and allow it to hang out from the platform suspended at a relatively constant slope.

The inner and outer surfaces of the pipe must be coated to prevent corrosion. Rubber coatings and other protection coverings have been used for many years on undersea pipes and cables, so this should be no great problem.

The double wall pipe with foam inner lining accomplishes two more objectives in the pipe construction:

1. It provides ring stiffness, so that the pipe will maintain a circular shape without collapsing, even if made in very large sizes.

2. It takes care of the insulation problem, preventing warming up of the cold water as it flows up through the warmer

layers. This is not a great problem in large plants, but could have been one in the rather small plant proposed by the French.

Another problem with the floating plant is that of keeping it at a fixed position. This can be accomplished as shown on fig. 7 by putting electric driven propellers or water jets ar various depths on the plant. These can be controlled automatically to keep the plant located. The position can be fixed by radio or radar triangulation to two shore stations using an antenna and receiver on the structure. The upper propellers or jets can control the position of the structure, since the maximum wind, current, and wave forces are there. The lower thrust unites can be controlled to keep the plant vertical in the water, or to a prescribed slope to line up with the natural slope of the pipe. The exit water from the condenser and evaporator may be directed downstream to act as a large stabilizing water jet.

In order to reduce the stress at the junction of the pipe and the structure, it may be advisable to put small pipes on the outside of the cold water pipe. These can extend downward to perhaps a hundred feet below the bottom of the structure. They can have open jets at their ends directed radially outwards. By pumping water through them, as dictated by stress sensing controls on the pipe the bending in this part of the pipe can be kept within a maximum allowable value. Below this point, the pipe can hang at its natural slope as explained above.

The maintenance of the underwater part of the pipe and structure is made possible by the many advances in underwater diving technology.[22]

To sum up the design problem, the floating plant seems to be the logical one for the Florida Straits, and there do not seem to be any insurmountable problems. The main difficulty seems to be the huge size of the turbines, and the removal of dissolved gases. This will not be dealt with here, but the French seem to have been satisfied with the possible solutions to these problems.

Economics

An economic analysis of the electric power production industry is now required.

Much money is being spent on the engineering and promotion of nuclear power plants. The average size of steam generating plants is increasing.[23] Pooling techniques are being perfected and used almost universally. This makes larger and larger plants practical and economical.

Costs estimates of these larger plants have been made for the purpose of showing that nuclear plants become less expensive than conventional steam plants as the size of the plants increase. A plot of the costs of nuclear and conventional plants is made in fig.10. These optimization curves include the totals of construction and fuel costs. They take into account the costs of added reserves as the size of plant increases plus the dependence of the capacity factor upon the installation of new plants.

The curves show that conventional plants have a minimum production cost per kilowatt at about 600 MW while the nuclear plants costs are still decreasing at 800 MW. While these very large plant costs may be less per KW hr. than for smaller plants, it should be noted that distribution costs will obviously go up, when too large a plant for a local consumption area is built. We can expect that these cost estimates may change with time and with more actual plants in service. However, for comparison these will be used at present.

The cost of fuel in a sea thermal power plant is 0. Let us see what we could afford to spend to build a sea thermal power plant to make it competitive with the nuclear plant costs from the curve.

$$(\text{mills/Kwhr}) \times (10^{-3}) = \text{dollars/KWhr.}$$

$$(\text{dollars/KWhr}) \times (\text{hours/year}) \times (.80) = \text{dollars/KW year}$$

load factor (.80)

$$\frac{\text{dollars/KW year}}{.14/\text{year}} = \text{dollars/KW}$$

14%/year = carrying charge

For example at 600 MW size dollars/KWhr = .00620

$$.00620 \times 8760\text{hours/year} \times .80 = \$43.40/\text{KW year}$$

$$\$43.40/14 = \$310/\text{KW}$$

Then for a 600 MW size plant we could afford to spend $310/KW to be competitive with an equal size nuclear plant. Note that even higher costs than this seem to have been justified for hydroelectric plants. For example, a recently built plant at Karibe Dam in Africa was built at a cost of $378 per KW. in a 600 MW plant.[24]

An S. T. E. plant proposed by U. S. Industries is estimated to cost $310 to $375 per kilowatt for a 5000KW net plant.[25] This is much smaller than the nuclear plant sizes plotted in the cost comparison curves. The S. T. E. cost is plotted on the optimization curve graph, Fig 9. Curves are projected from the upper and lower bounds of the U. S. Industry estimate. The S. T. E. plant costs should decrease with increasing size just as nuclear or conventional plants do. Just as an example for a cold water pipe twice the diameter of another, the volume of water brought up is 4 times that brought up in the first pipe. Also the efficiency of pumping water rises with a larger pipe since the resistance to flow per volume of water decreases with an increasing diameter pipe.

$$R_e = \frac{Vd}{\nu} = \text{REYNOLD'S No. for a pipe of } d_1 = D$$

ν = KINEMATIC VISCOSITY
V = VELOCITY
d = DIAMETER

if $d_2 = 2D$ and $V_1 = V_2$

$$R_e = \frac{2VD}{\nu}$$

$$\text{Head loss} = h = f \frac{L}{d} \frac{V^2}{2g}$$

where f is the friction factor
L = LENGTH g = ACCELERATION OF GRAVITY

$$f \sim \frac{1}{R_e}$$

If roughness, velocity, and the unit length are kept constant but d changes from $d_1 = D$ to $d_2 = 2D$ R_e increases. This causes f to decrease (as long as flow is well into turbulent region). Also from the head loss equation we see that the increase in d directly decreases h by the factor of increase in d. Thus it is much to our advantage to increase the diameter of the pipe.

Since pumping power is a head loss, any decrease in this power is a direct gain in power output capability of a given size turbine. This means that the cost per net kilowatt goes down as the pipe size goes up. The cost of the floating structure per kilowatt also obviously goes down as the size goes up. Therefore, we can consider the down slope of the projected cost curve for Sea Thermal slants as being very well adjusted.

The large nuclear plants proposed on the plot still have not been realized. As of 1960 only five nuclear power plants the largest of which is 60MW and 4 small ones of 2 to 6.5MW were in operation. 16 other nuclear plants were in either construction or repair status and expected to be in service in 1961 to 1963. The largest of these is 275MW and the rest vary down to 3250KW.[26]

So we see that Nuclear Power plants have a lot of growing to do. The S. T. E. proposal of a 5000KW plant is comparable in size to quite a few of the present Nuclear Power plants.

We cannot escape the conclusion then that S. T. E. plants should receive the same amount of research and engineering being applied to Nuclear power. While nuclear plants may become economically feasible we should remember that the great problem of disposal of radioactive waste is still an unsolved and expensive problem. This problem doesn't exist with S. T. E., nor does any operating or explosion hazard exist.

Conclusion

It is seen that the Straits of Florida between Miami and the island of Cat Cay provide an ideal location for a floating S. T. E. plant. There is a growing need for power in the Miami area.

A comparison of nuclear power plant costs and S. T. E. plant costs indicates that they can be competitive dollar wise. Since thermal energy from the sea has fuel costs of $0 and is potentially competitive and feasible, why should we not spend as much money upon it as upon nuclear power?

It has infinite potential for a permanent supply of power from the sun, beyond our conceivable needs, and there is no hazard involved. Perhaps it doesn't sound as glamorous as nuclear power, but the feeding and living standard of the world's expanding populations seems to me to be far more important.

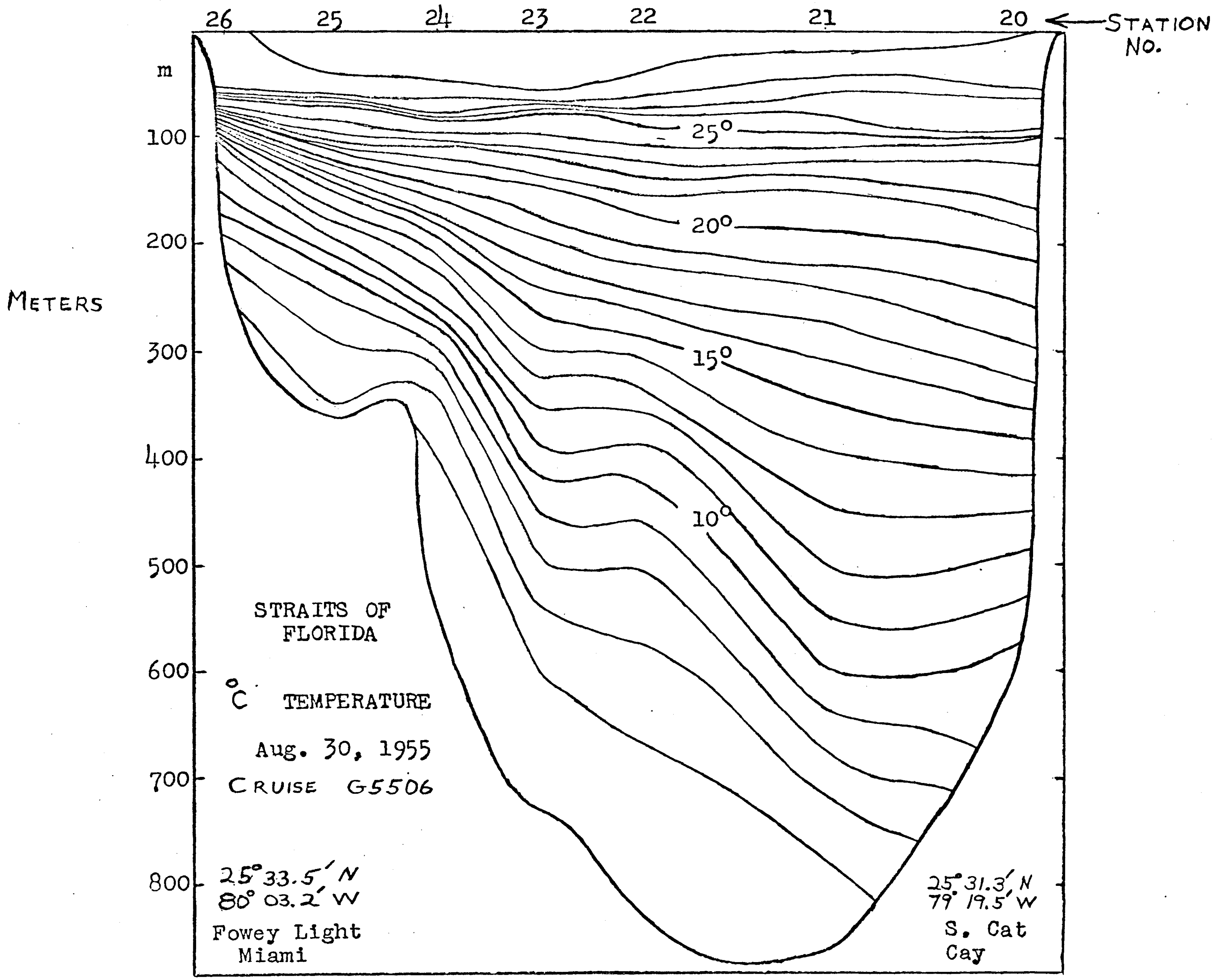


FIG. 1

REF. No. 16

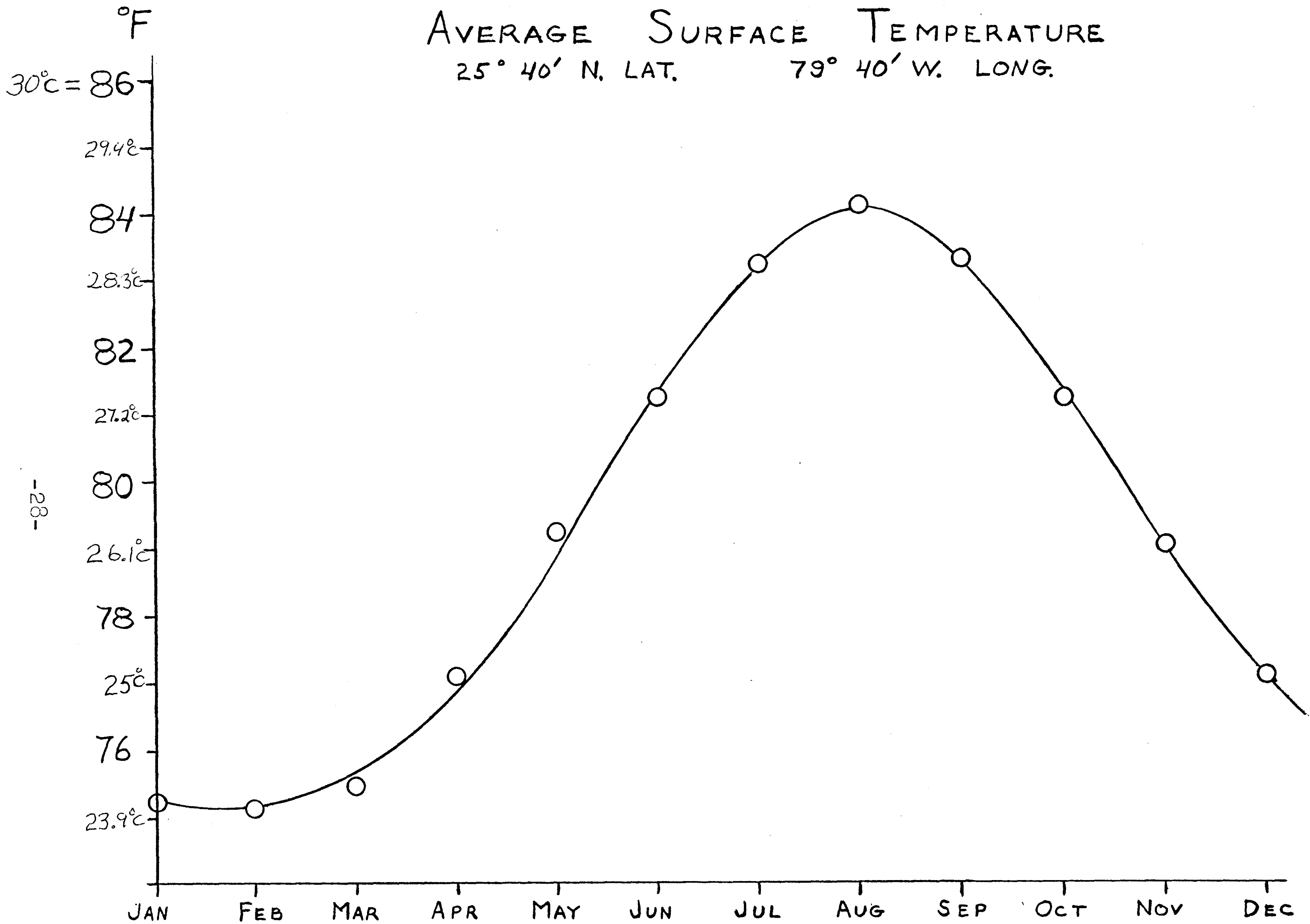

AVERAGE SURFACE TEMPERATURE
25° 40′ N. LAT. 79° 40′ W. LONG.
°F
30°C = 86
29.4°C
84
28.3°C
82
27.2°C
80
26.1°C
78
25°C
76
23.9°C
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

FIG. 2

REF 11

Cost Per Kilowatt Hour For Fuel

Cents

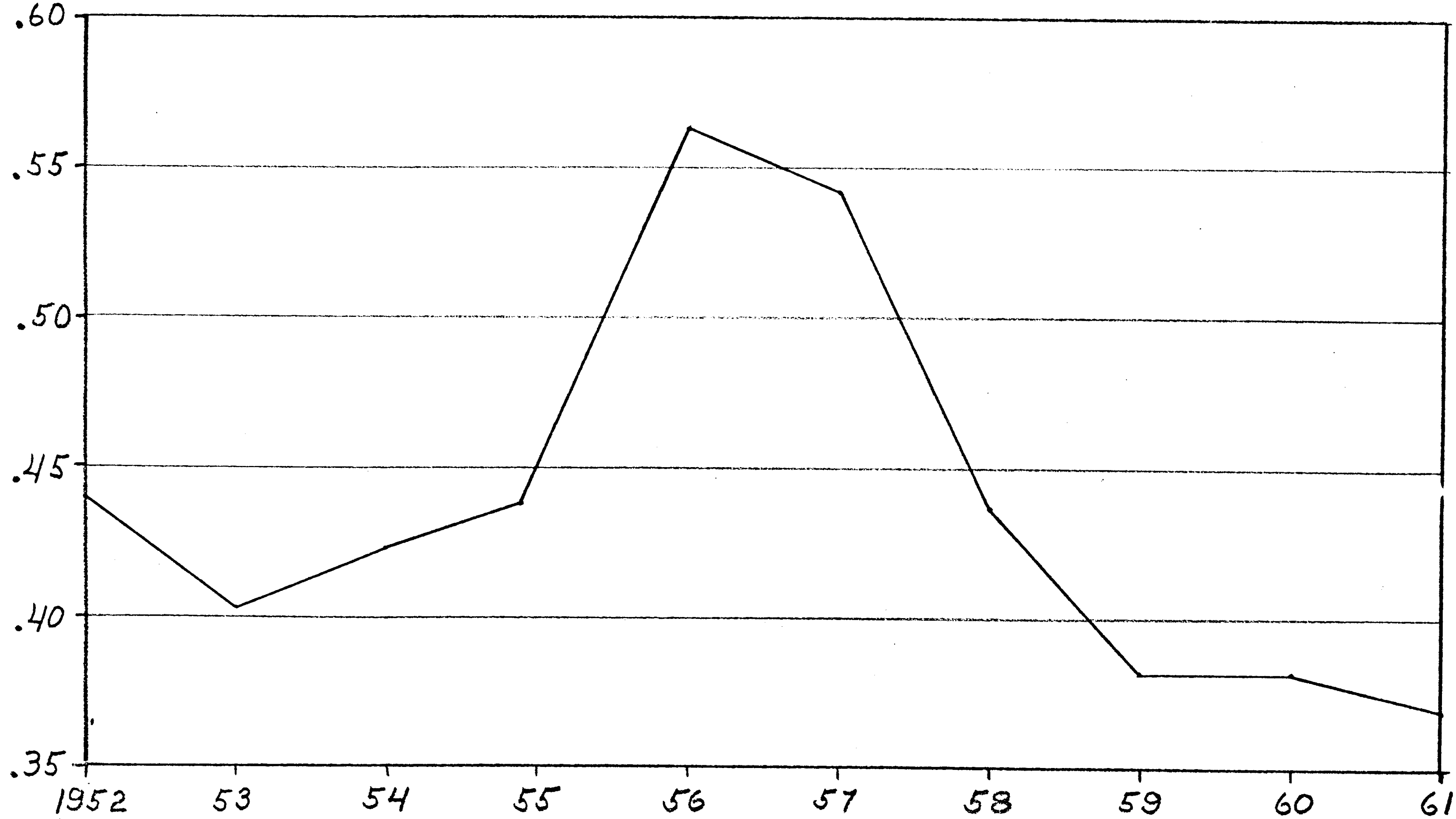


Fig. 3

Ref 49
P. 10

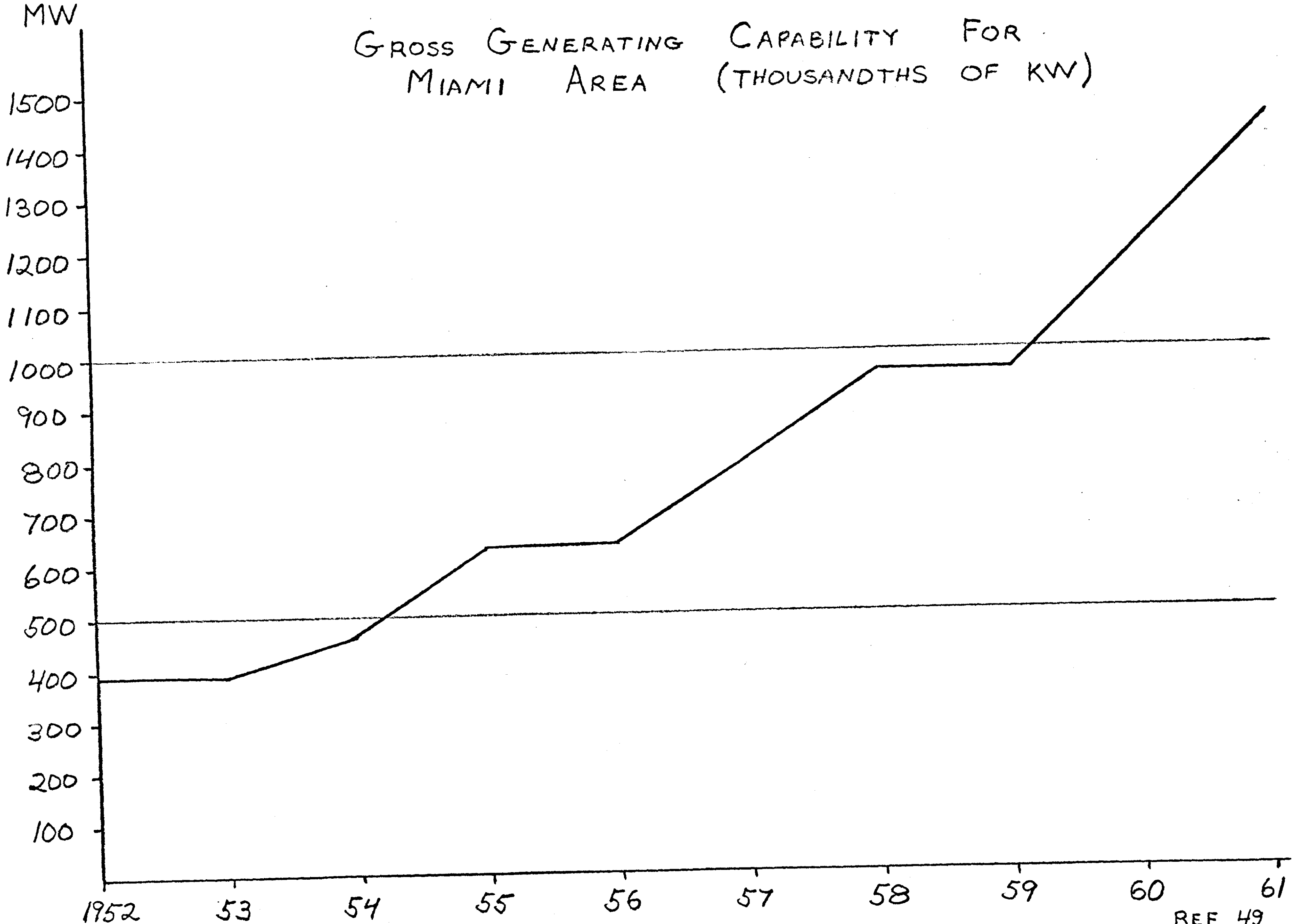


FIG 4

REF 49
P. 10

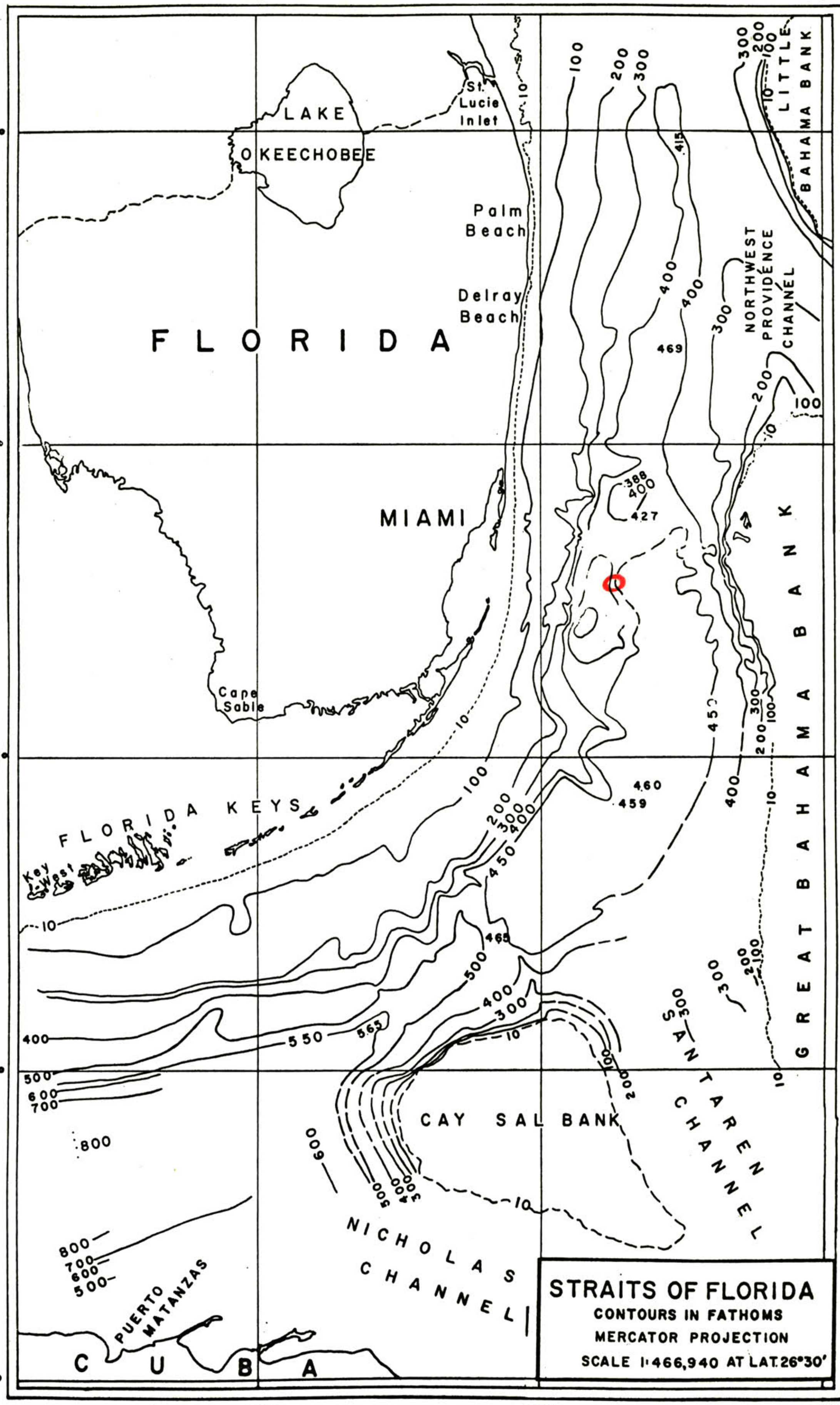

STRAITS OF FLORIDA
CONTOURS IN FATHOMS
MERCATOR PROJECTION
SCALE 1:466,940 AT LAT. 26°30'
FLORIDA
LAKE OKEECHOBEE
St. Lucie Inlet
Palm Beach
Delray Beach
MIAMI
Cape Sable
FLORIDA KEYS
Key West
CAY SAL BANK
NICHOLAS CHANNEL
SANTAREN CHANNEL
GREAT BAHAMA BANK
LITTLE BAHAMA BANK
NORTHWEST PROVIDENCE CHANNEL
PUERTO MATANZAS
CUBA
81°
80°
79°
27°
26°
25°
24°
23°

Figure 5

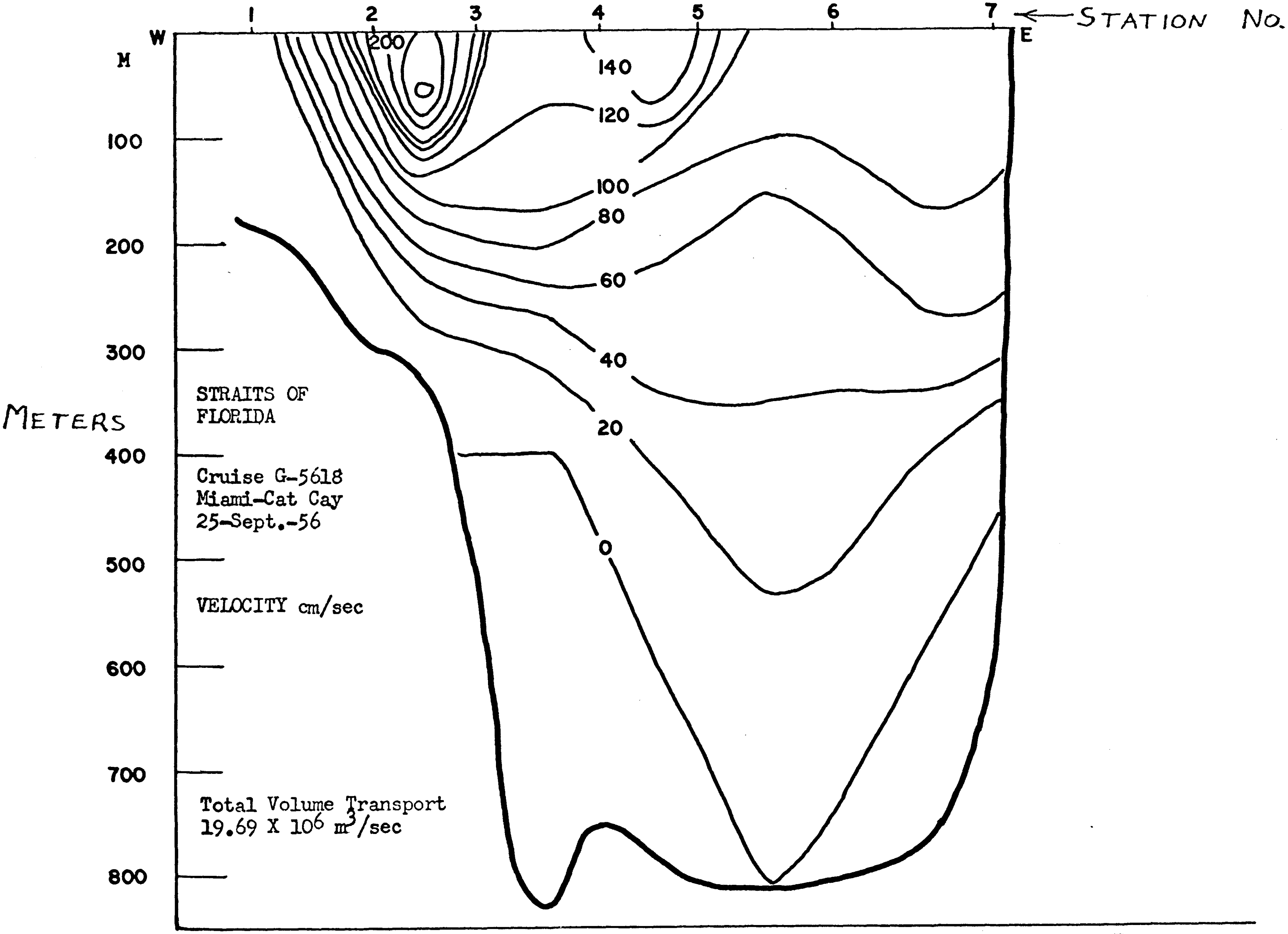


FIGURE 6

REF. No. 17
P. 31

Floating Structure for Dropping pipe in Ocean

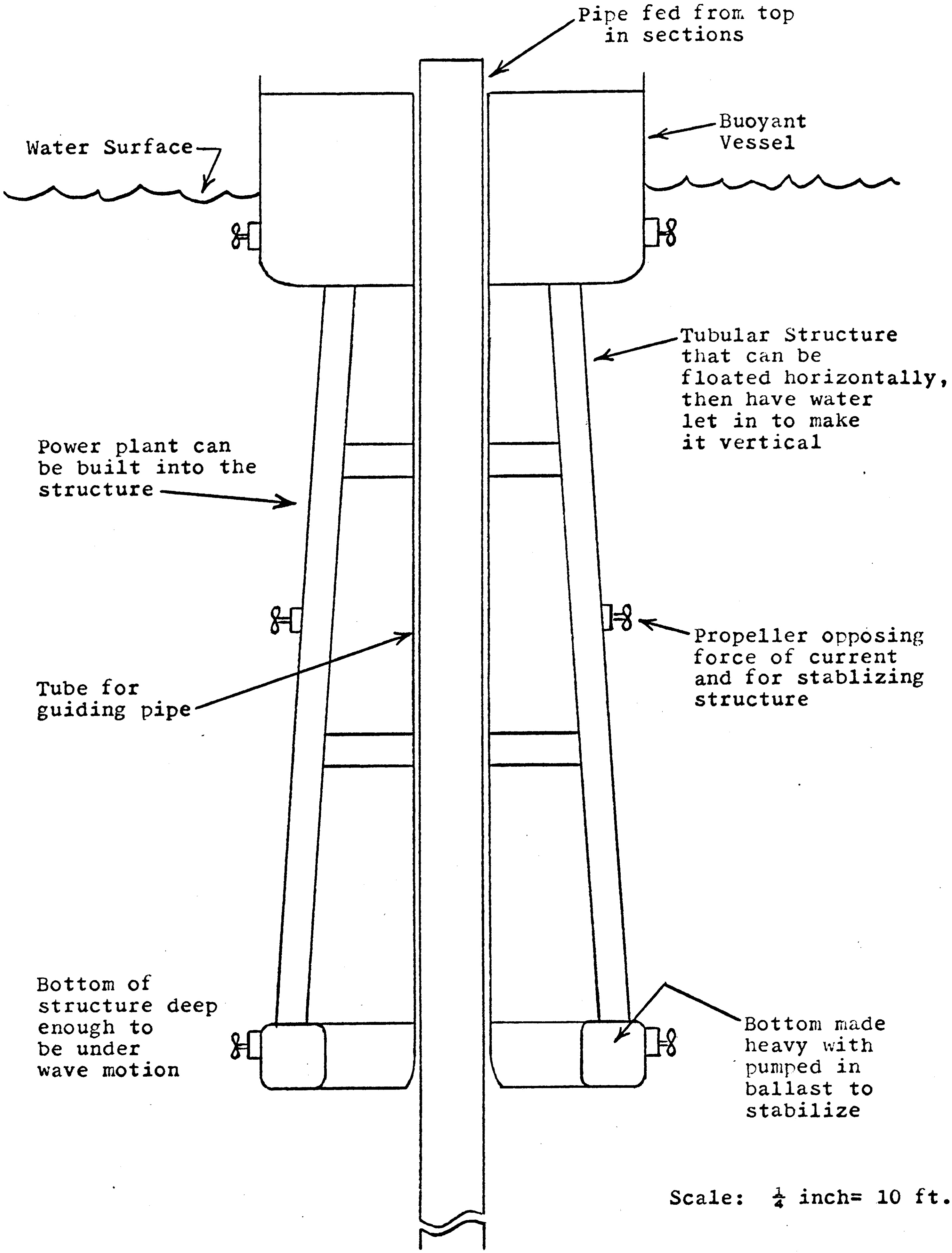
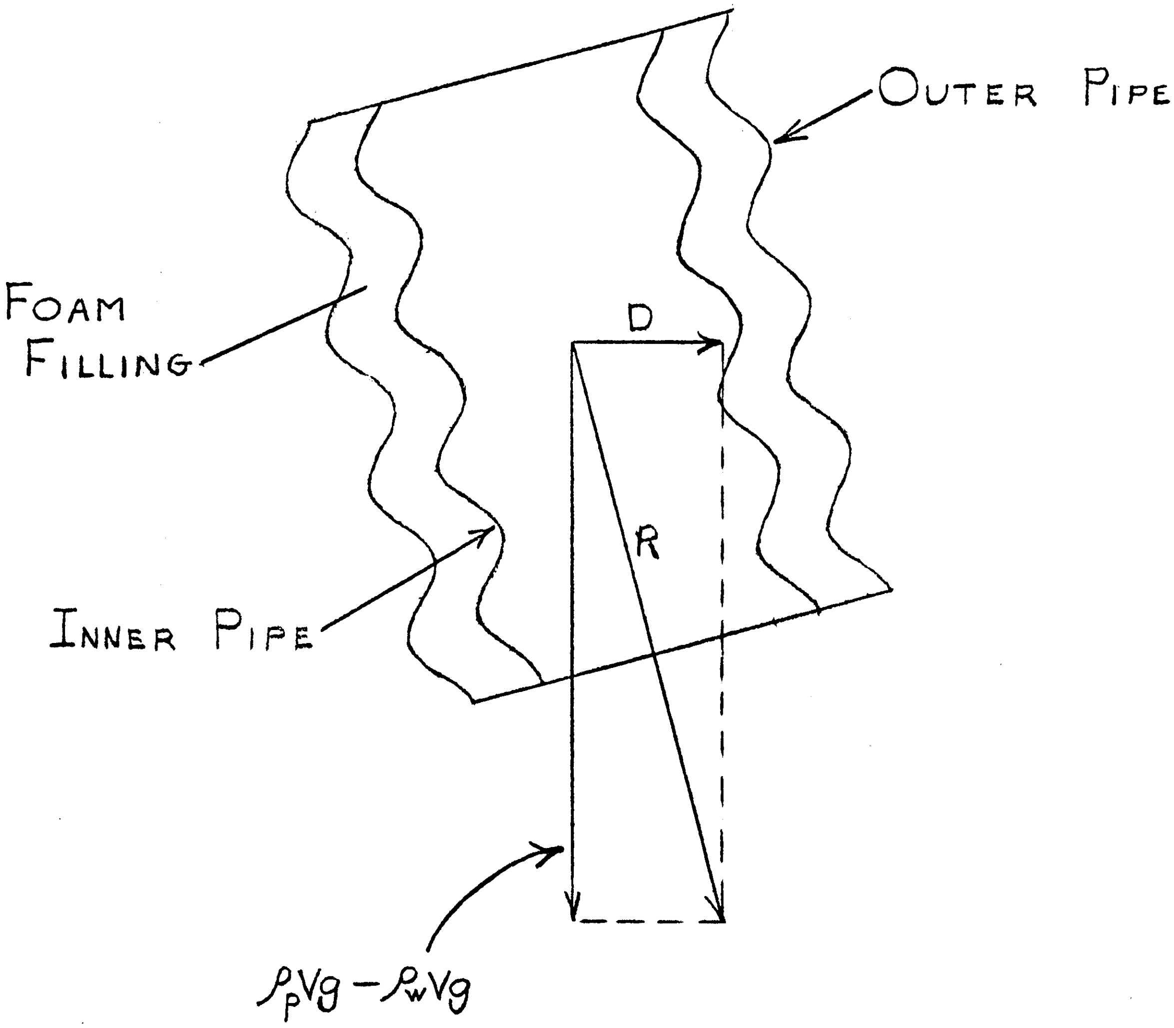


Figure 7

PIPE ELEMENT



ρ_p = DENSITY OF PIPE

ρ_w = DENSITY OF WATER

V = VOLUME DISPLACED BY PIPE

g = ACCELERATION OF GRAVITY

D = CURRENT DRAG

R = RESULTANT OF FORCES ON PIPE SECTION – ALONG PIPE AXIS

FIG 8

Optimization Curves I
Cost For Sea Thermal Energy Plant

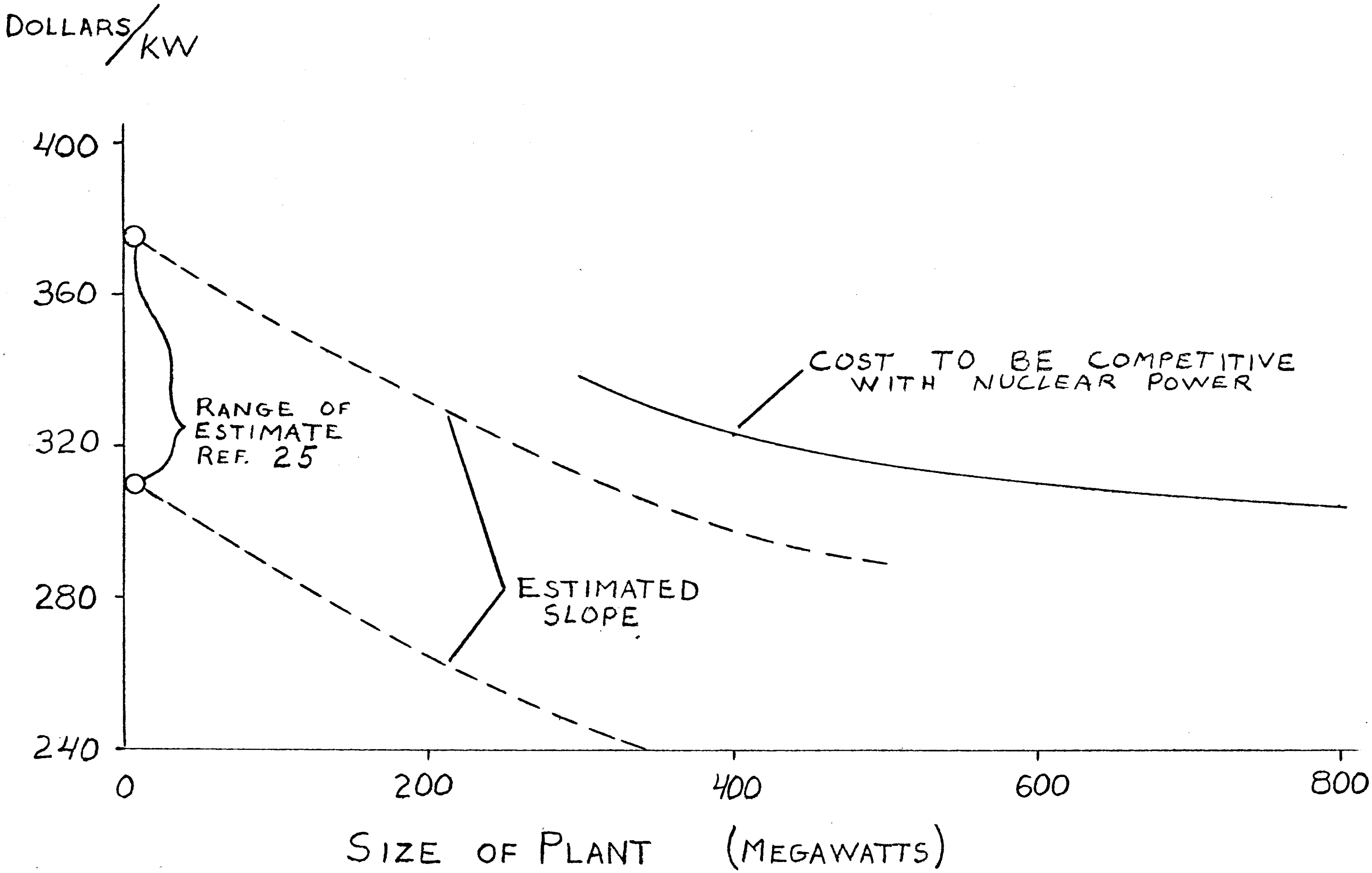


Fig 9

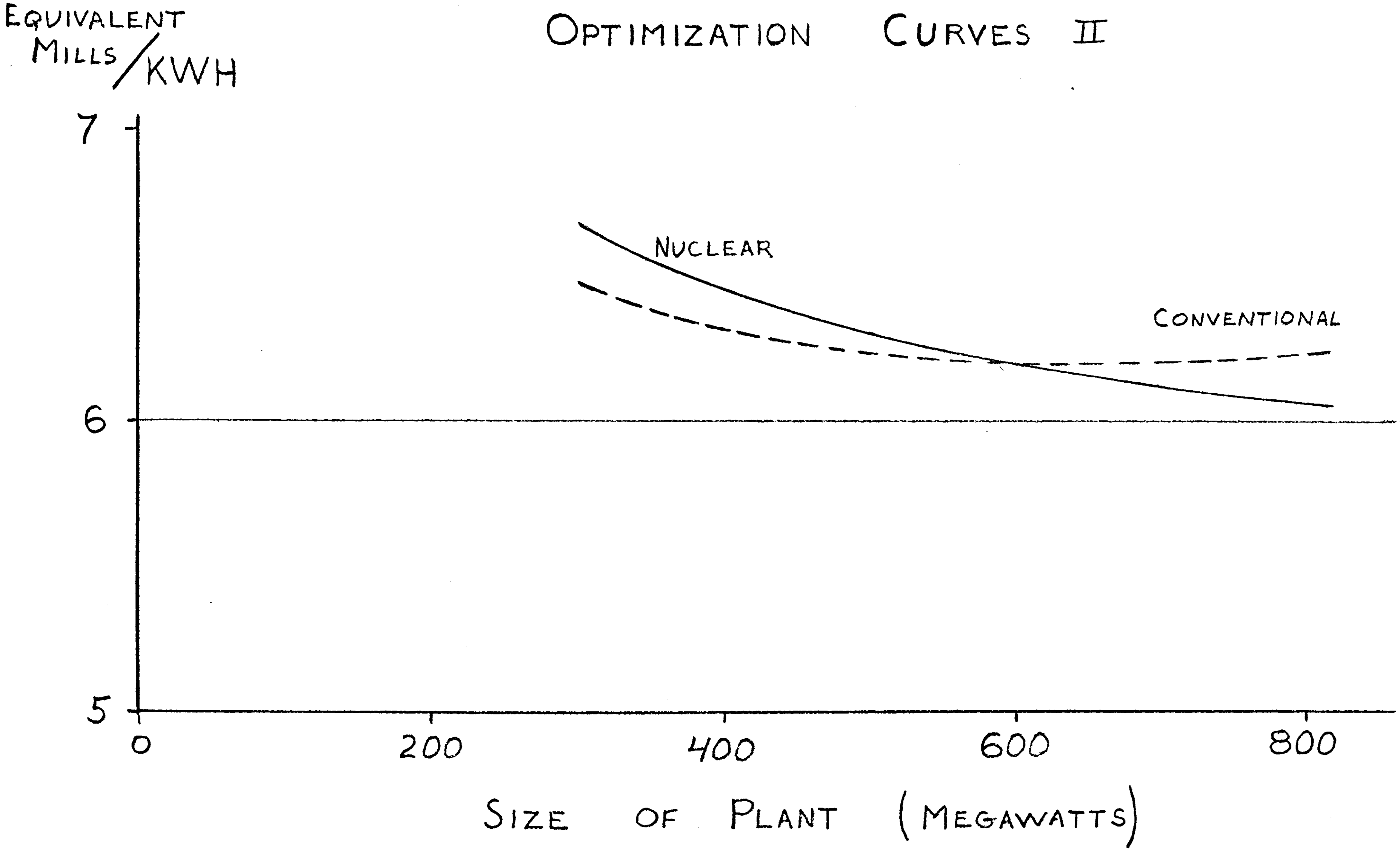


Fig. 10

Ref. 54
P. 64

NOTES

1. Ref. 56
2. Ref. 25, page 49
3. Ref. 29, page 702
4. Ref. 38, page 1040
5. Ref. 42
6. Ref. 30, page 687
7. Ref. 29, page 704
8. Ref. 26, page 104
9. Ref. 33, page 4
10. Ref. 34, pages 3-4
11. Ref. 11 and 12
12. Ref. 49, page 14
13. Ref. 52
14. Ref. 43, page 47
15. Ref. 31, page 226 and Ref. 37, pages 796-808
16. Ref. 36, page 862
17. Ref. 33, page 8
18. Ref. 34
19. Ref. 55, page 43
20. Ref. 59
21. Polyurethane foam should be better than styrofoam as it is tough, flexible and very resistant to attack. It can also be made in almost any density, as low as 5 pounds per cubic foot.
22. Ref. 58
23. Ref. 45, page IV
24. Ref. 57
25. Ref. 25
26. Ref. 45, page VII

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