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PRELIMINARY ECONOMIC REPORT ON THE APPLICATION OF ATOMIC POWER TO MERCHANT SHIPS. PART I. MIXED DRY CARGO SHIPS

By
W. J. Burns, Jr.

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Preliminary Economic Report on the Application of Atomic Power to Merchant Ships

Part I

Mixed Dry Cargo Ships

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REVIEWED BY M.L. IRELAND, JR.   PREPARED BY W.J. BURNS, JR.

NEWPORT NEWS SHIPBUILDING AND DRY DOCK COMPANY

ATOMIC POWER DIVISION

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(a) Interim Technical Report, No. NNSD 9 issued to the Atomic Energy Commission by Newport News Shipbuilding and Dry Dock Company.

(b) U.S. Merchant Marine Act, 1936 and as revised.

(c) Revision of Essential U.S. Foreign Trade Routes - Introduction USMA dated May, 1953

(d) Cargo Handling and its Relation to Overseas Commerce, By - Arthur C. Rohn, Society of Naval Architects and Marine Engineers, Transactions Vol. No. 53, 1945.

(e) U.S.M.A. letter dated December 28, 1954.

(f) Operation in Service of the Marine Type Ship, By William G. Allen and E. Kemper Sullivan - Discussion by L. H. Quackenbush, Society of Naval Archietects and Marine Engineers, Transactions, Vol. No. 62, 1954.

INTRODUCTION

The Newport News Shipbuilding and Dry Dock Company has been vitally interested in nuclear power plants as applied to ship propulsion since 1952. The first efforts of the company were toward naval applications under the CVR Project which was started in 1952 and terminated in July, 1953. On November 4th, 1953, the company signed a study agreement with the Atomic Energy Commission to investigate various problems associated with a nuclear propulsion program. Under this agreement, work has been concentrated on merchant ship propulsion.

The first phase of this study was an evaluation of the machinery weight and space requirements of a nuclear powered merchant ship. Preliminary reactor plant designs were prepared for ships in the following horsepower ranges: 12,000 SHP, 22,500 SHP, and 50,000 SHP, per shaft. The total and specific machinery weight, and space required, were compared for each with an oil-fired counterpart. The 22,500 SHP reactor plant was selected for refinement into a reference design for use in a study of the nuclear power problems which appear to be unique to merchant ship propulsion, reference (a).

With the reference design available the over-all study was implemented by a study of American merchant ship economics. The economic study was restricted to merchant cargo operations in the three main categories, namely, mixed dry cargo, oil tankers and ore ships. In the mixed dry cargo operations the ships considered were the: C2 - 6000 SHP; C3 - 8500 SHP: and the Mariner - 22,000 SHP.

Scope

The mixed dry cargo ship operations were first considered as it was felt that a nuclear propelled ship would be in line with the stated U.S. Maritime policy of fostering not only a strong merchant marine, but of providing for and protecting certain dry cargo trade routes considered essential to our national economic welfare, reference (b).

The oil trade routes were investigated because, it was evident that tankers can take better advantage of the inherent capabilities of a nuclear plant since their port time is very small in relation to over-all voyage time. However, the fact that the cargo moves only one way must be considered.

The ore trade routes will be limited to the iron ore and bauxite ore trades as they are the major ores that move in ship load lots. Other ores, while they have more value, move generally as a partial cargo in the mixed dry cargo trade.

The U. S. Maritime Administration was approached on July 15, 1954, as to the willingness of the Administration to furnish certain economic and trade information dealing with mixed dry cargo operations on essential trade routes. The Administration indicated a willingness to furnish the requested data and has been very helpful in all phases of the work dealing with mixed dry cargo operations. Since the mixed dry cargo ship study is substantially complete it is embodied in this report as Part I of the economic study.

Mixed Dry Cargo Operations

The first approach to this segment of the economic study was an examination of the 31 trade routes which are considered to be essential by the U. S. Maritime Administration, reference (c).

To each trade route was applied the two criteria needed to best determine the nuclear ship advantages. These two criteria are, long distance, (over 10,000 miles for round trip) and a substantial dead weight or cubic cargo. The examination of the trade routes showed that there were possibilities on several of these in which the distance varied from approximately 15,000 to 30,000 nautical miles. Five trade routes were chosen for analysis which involved eight companies. Economic information on these five trade routes was obtained from the U. S. Maritime Administration on typical voyages of the company serving the route. However, the data obtained was primarily aimed at weight and distance factors rather than operating costs. The data also was limited to one or two voyages on each route for each size ship. For this reason the operating cost data contained a great number of irregularities and did not appear to give average costs.

On the basis of the analysis of the trade and economic information obtained from the U. S. Maritime Administration, our study has been narrowed down to two trade routes and three companies. The three companies were contacted as to their willingness to give average industry cost and trade figures on their particular trade routes. Information obtained from these sources will be incorporated in separate reports.

There are certain difficulties in comparisons between trade routes; union agreements, stevedoring rates, operating policies, cargo available, etc., all of which vary between the companies so that only rough correlations are available. It is felt that if the three companies involved are willing to furnish annual operating cost data a much more accurate picture can be obtained of present operations. Knowing present operating costs for two or three different sized ships, it should be possible to examine each factor and see whether or not costs will be lower, be the same or be higher for a nuclear powered plant. As the end result, the permissible cost of a nuclear plant for a ship can be determined.

Deadweight and Cubic Capacity

One of the advantages hoped from a nuclear powered ship is an increased cargo capacity when the steaming or fueling distance is greater than the break-even distance. The break-even distance is defined as that distance at which the weight of machinery and shielding for the nuclear plant is equal to the weight of the oil-fired plant plus the weight of the fuel oil required to travel this distance.

The machinery weights for both nuclear and oil-fired plants have been estimated for the three types of ships, C2, C3 and the Mariner and in addition for the C3-S-DX, 12,500 SHP which was a prototype ship. Reference (a) was used as the basis for estimating machinery weights which are tabulated below:

Ship Type	Rated SHP	Machinery Plant Weights Nuclear	Oil-Fired	Diff.
C2	6000	1045 Tons	535 Tons	510 Tons
C3	8000	1290 Tons	702 Tons	588 Tons
C3	12500	1586 Tons	834 Tons	752 Tons
Mariner	17500	2023 Tons	1040 Tons	983 Tons

The difference between the nuclear machinery weight and the oil-fired machinery weight is the weight of oil required to reach the break-even distance. Beyond the break-even distance there is a dead weight advantage which **accrues to the** nuclear ship over the oil-fired ship, which is equal to the difference (expressed in tons of oil required) between the break-even distance and any greater steaming distance. This advantage is maximized at the steaming distance of the oil-fired ship based on full fuel oil tank capacity. The break-even distance and maximum possible gain in deadweight tons is given below for the four types of ships:

Ship Type	Fuel Oil Cons./Day	Break-even Distance *	Max Deadweight Gain	% of Ship Deadweight
C2	32.8 Tons	4660 Miles	1234 Tons	11.4
C3(8500SHP)	43.6 Tons	4460 Miles	1037 Tons	8.5
C3(12500SHP)	58.5 Tons	4750 Miles	1556 Tons	14.8
Mariner	84.0 Tons	4710 Miles	2825 Tons	21.1

* Fuel Oil Margin Included

The above tabulation indicates that a nuclear ship has a comparatively short break-even distance and that the maximum possible gain in deadweight is appreciable with the Mariner ship having the greatest deadweight advantage. While the tabulation indicates that beyond the break-even distance there is a deadweight advantage available, it is well to point out that the actual amount of cargo deadweight used is dependent on the type of cargo loaded. Thus, to use the added deadweight available beyond the break-even distance, a cargo blend must be assumed which will put the ship down to the loaded draft marks. This is rarely the case as shown by Table I.

On a round trip or voyage basis the break-even distance is increased due to the fact that the oil-fired ship loads oil in only one port while it discharges and loads cargo in two ports. Thus, on the return half of the voyage distance, the cargo deadweight can be increased equal to the amount of oil needed to reach the foreign port. In contrast the nuclear ship has a fixed amount of machinery weight which does not vary with the distance travelled. The break-even distance in a round trip or voyage basis is as follows for the four types of ships considered:

Ship Type	Break-even Distance Round Trip Voyage Basis *
C2	5980 Miles
C3 (8500 SHP)	5650 Miles
C3 (12,500 SHP)	6080 Miles
Mariner	6025 Miles

* Fuel Oil Margin and Port Time Included

An indirect advantage which accrues to the nuclear ship is a gain in cubic capacity which can be readily evaluated in terms of potential increased revenue. The gain in cubic capacity comes as the result of the elimination of the fuel oil deep tanks which are not needed by the nuclear powered ship. Therefore, while up to the break-even distance the nuclear ship has a dead weight penalty, it has a cubic capacity gain.

Beyond the break-even distance the nuclear ship has a dead weight and cubic capacity gain. The gain in cubic capacity for the C_2, C_3 and the Mariner is as follows:

Symbol	Ship Type	F.O. Cap. Tons	B.C. Cap. Cu.Ft.	Fuel Oil Deep Tk Capacity Tons	Fuel Oil Deep Tk Capacity B.C. Cu.Ft.	Total B.C. Capacity Cu. Ft.	Gain in B.C. %
A	C_2-S-AJ1	1744	542,824	317	8,550	551,374	1.8
B	C_2-S-AJ5	2155	509,787	729	19,650	529,437	3.9
C	C_3-S-AJ2	1625	736,850	112	3,000	739,850	0.5
D	C_3-Mod.	3454	687,350	1941	52,500	739,850	7.6
E	Mariner	3808	766,977	1290	34,800	801,777	4.5

* 27 cu. ft. per ton used
as conversion factor

The above tabulation indicates that for the standard design, "A" and "C", the gain in cubic capacity is negligible. The round trip steaming distances of these ships are approximately 18,000 and 15,000 miles respectively. In order to increase the steaming distance of these vessels additional fuel oil deep tanks were added to many C-2 and C-3 ships as indicated by "B" and "D".

Deadweight and bale cubic capacity were sacrificed and this shows up as an appreciable quantity which can be economically credited to the nuclear ship, as it does not require any fuel oil deep tanks. The Mariner ship, "E", also shows an appreciable increase in bale cubic capacity with the elimination of fuel oil deep tanks.

It may be pointed out that the gain in cubic capacity generally will result in a higher revenue than the penalty (loss of revenue) paid in deadweight (up to the break even distance) due to the normally higher tariffs on measurement (cubic) cargo.

The gain in cubic capacity up to the break-even distance and the gain in deadweight beyond this point is of particular interest to American ship operators. Mixed dry cargo has usually tended to be space cargo rather than weight cargo. This is particularly true of out-bound cargoes which are generally manufactured products, while inbound cargoes may tend toward weight cargoes since they are primarily raw materials. The manufactured products of outbound cargoes are generally measurement (cubic) cargo and therefore can take advantage of the gain in cubic capacity (due to the fuel oil deep tank elimination) without paying the penalty for the increased weight of the nuclear ship. On the inbound passage the oil fired ship usually carries only enough oil plus a margin to enable the ship to reach the first discharging port. If, on this basis, the inbound passage distance exceeds the break-even distance and the inbound cargo is a weight cargo, there is a cargo dead weight advantage plus a cubic capacity gain which may be used if feasible.

In summary then we may say that the nuclear ship requires an out-bound cargo with a higher density factor up to the break-even distance. Beyond the break-even distance the nuclear vessel's cargo should tend toward a weight instead of cubic cargo as the outbound passage distance increases due to the greater gain in deadweight as against the gain in cubic capacity. Inbound cargoes should be low density factor cargoes. The voyage distance for the nuclear ship should be more than the round-trip or voyage break-even distance and, for maximum deadweight and cubic capacity benefit, should be equal to twice the steaming distance of the oil-fired ship as represented in the fuel oil tank capacity of the oil-fired ship.

Typical data obtained from the Maritime Administration and summarized in Table I discloses two Trade Routes, (A) and (C),which, out bound, run to full cubic cargoes and could take credit for any cubic capacity advantage established for a nuclear powered ship. Trade Route (C), out bound, could, in addition to a cubic capacity gain, take credit for any increased cargo deadweight established for a nuclear powered ship. On the inbound passage only Trade Route (B) is attractive due to the cargo deadweight tonnage utilization.

Time at Sea

The time at sea factor is an indirect indication of where a nuclear powered ship might be applied to advantage.

This is because a high time at sea factor means more fuel oil is burned per year at a given speed which in turn means an increase in the amount of money that can be saved, or capitalized in a nuclear powered ship.

The mixed dry cargo common carrier is at a disadvantage in this respect due to the multiplicity of foreign ports that it has to visit, plus the coastal ports of call. This, plus the time spent in each port unloading cargo, cuts the time at sea so that it rarely exceeds 75% and generally is about 50-55% as compared to 83-87% for an oil tanker. The increased speed of larger ships has generally resulted in a lower time at sea factor since the time in port has remained constant or increased. Table II indicates that this is so for the Mariner type ships which are spending relatively more time in port resulting in a lower time at sea factor. This indicates that the nuclear cargo ship design must also employ a new approach to cargo handling for the ship to fully benefit from any possible increase in speed.

Costs - General

1. The major savings of a nuclear powered ship will be the cost of the oil burned in a conventional ship. For this reason the most attractive cargo ship for a nuclear application is the Mariner ship which is a 20 knot - 17,000 SHP ship designed to be not only a large merchant ship but also a fleet service unit in time of war. On the basis of a 70% time at sea factor the fuel bill of a Mariner is approximately $310,000 per year. This value when amortized gives a permissible increase in first cost of approximately 3.7×10^6 dollars. The only vessel operating data available gives a time at sea factor of under 50% for a Mariner. This results in a fuel bill of $233,000 per year with a permissible increase in nuclear plant cost of 2.78×10^6 dollars.

2. Conventional boilers stacks, fuel oil burning and storage facilities are not required in the nuclear ship and these savings should be deducted from the cost of the nuclear plant.

3. Wage costs are estimated to be approximately $20,000 per year higher than with conventional plants. A nuclear plant requires no firemen-water tenders but would require three licensed reactor-engineer operators and one additional first assistant reactor engineer. The four men would require additional training and it is assumed that the three would be the equivalent of senior third assistant engineers while the fourth would be the equivalent of a first assistant engineer. The reactor operators, while having special training in operating the reactor, would not be required to know reactor

theory. The reactor engineer would be required to have some nuclear engineering and reactor theory and be responsible for the maintenance and repair of the equipment within the shield.

4. Subsistence would be the same as with an oil fired plant.

5. Under stores, supplies, equipment and maintenance costs, the only costs that might change are those for the Engine Department, and within this department, only steam generation maintenance. Thus the maintenance of the reactor and its equipment are to be evaluated in comparison with conventional boiler maintenance. The cost of equipment and parts replacement might be higher for a nuclear plant. However, this may be compared with the large labor cost for frequent cleaning of conventional boilers. Preventive maintenance is felt to be an essential feature in operating a nuclear plant.

General Results for Mixed Dry Cargo Operations

During the initial phase of the economic study efforts were made to show actual cost per mile and actual cost per ton as a function of round trip distance. The costs were taken from voyage data as reported by various operating companies to the USMA. The results of these efforts are shown in Curve Sheets "A", "B", "C" and "D". Curve Sheets "A" and "B" are based on ship expense only as defined in Table III while Curve Sheets "C" and "D" are based on total ship operating expense including actual cargo and our estimate of fixed charges which were not supplied by MA. Due to the many variables involved such as voyage speed, port dues, brokers fees, number in the crew, union agreements, fuel cost per barrel, etc., the results were considered inconclusive. For instance it is seldom possible to fit a curve to the actual data which will agree in shape with the theoretical curves shown. (The bases for the theoretical curves are described in Appendices A, B and C). Therefore a new approach was undertaken.

After discussing the above work performed up to December 1st, 1954 with USMA personnel, a new analysis was made based on average per diem costs. These average daily costs were used to determine ship expenses for calculated boyages and this data was plotted for the C2, C3 and Mariner ships using various time at sea factors. The rated speed of the vessels was used. Fuel oil costs were obtained and plotted on the same basis. See Curve Sheets "E" through "K". These results give a straight line relationship between both ship expense and fuel oil cost per voyage and miles traveled for each of the various time at sea factors. In addition a cross plot was made of cost/year vs round trip voyage distance using various fixed days in port.

From the fuel oil cost/year plotted against distance it is possible to calculate the approximate permissible investment for each ship with various time at sea factors according to the following formula:

$$I_A + .02\ I_A \times 20 + .0138\ I_A \times 20 = 20\ \left(\frac{\text{Fuel Cost}}{\text{Yr}} - 20{,}000\right)$$

$$I_A = 11{:}90\ \left(\frac{\text{Fuel Cost}}{\text{Yr}} - 20{,}000\right)$$

I_A = Permissible Additional Investment for Atomic Reactor, fuel, boilers and associated equipment including shielding.

This formula is based on the following data:

1. Interest: USMA gives a 75% mortgage at 3- 1/2% which results in an average rate of interest of .0138%/Yr.

2. Insurance: Assumed 2%. U. S. Government to assume any catastrophe risk.

3. Depreciation: Straight 5% per year.

4. Wage Cost: Assumed $20,000 per year higher.

The permissible extra investment is shown graphically on Curve Sheets"F","H"& 'M" together with fuel oil cost per year.

Table No. IV shows the percent increased ship expense plus fixed charge costs per year of the C3 and the Mariner ship as compared to the C2 vessel for various time at sea factors.

From Table IV the yearly cost of a C3 ship is approximately 11% higher than that of a C2 ship and the cost of the Mariner is approximately 51% higher than that of a C2 ship in the range of normal operating time at sea factors. Thus the combined speed, cargo handling and size advantages of the Mariner ship must be such as to haul at least 51% more cargo per year if the ship expense per ton is to equal that for a C2 ship.

Table V shows the percent increased ship expense plus fixed charge costs per year of the C3 and the Mariner ship as compared to the C2 vessel when the comparison is on a maximum available sea time factor (100% cargo capacity) and voyage distance basis.

From Table V it is evident that on a 100% cargo basis the C3 and the Mariner ship must haul an increasing amount of cargo as compared to the C2 ship as the voyage round trip distance increases.

Two factors govern the amount of cargo which can be carried provided cargo is available. The distance traveled per voyage and the port time required to load and unload the vessel determine the number of voyages per year and thus the revenue tons which can be carried. Curve Sheet "O" shows the maximum calculated sea time factor for the three types of ships based on both 100% cargo capacity (Full and Down) and at 60% cargo capacity. Port times appropriate to the cargo carried per voyage were calculated as described in Appendix "D". Curve Sheet"O" shows that at a voyage round trip distance of 5,000 miles a fully loaded Mariner ship can have a maximum time at sea of 33.3% while the C2 and the C3 are 41.4% and 32.3% respectively.

At a 30,000 mile voyage distance the Mariner has a maximum available sea time factor of 76.1% while the C2 and the C3 ships are 81.7% and 75.6% respectively. The major value of this curve is to define the sea time factor and therefore the permissible investment as shown on Curve Sheets"F","J" and "M" in terms of the limiting factors for the voyage distance considered. Thus if the contemplated round trip voyage distance is 16,000 miles, the maximum sea time factor for the three ships is C2 - 70.0%, C3 - 61.8% and the Mariner 62.3% when the ship is full and down. Considering these percentages, the permissible investment for the 16,000 mile voyage distance is as follows: C2 - 1.25 million dollars, C3 - 1.54 million dollars, and 3.12 million dollars for the Mariner ship as shown by the cross plots on Curve Sheets"F","J" &"M". The maximum permissible investment which can be amortized for a nuclear power plant occurs naturally at the longest distance which for the Mariner ship at 30,000 miles results in a time at sea factor of 76.0%. This in turn gives a permissible extra investment of approximately 3.75 million dollars.

In our present study we have used maximum figures so that the results could show the maximum possible investment. Curve Sheet "G","K" &"N" gives permissible investment computed for 60% cargo capacity.

As a further development, revenue tons per year were computed for each class of ship (See Curve Sheet "P"). In these curves revenue tons per year is plotted against voyage miles for a series of time at sea factors. Each group of curves is cut off at the maximum available sea time factors and the cross-hatched area thus cut off is unavailable. The ship expense plus fixed charge cost per revenue ton has been plotted against voyage distances (Curve Sheet"Q"). Revenue tons have been used in these calculations as it takes into account both the deadweight available for cargo and the cubic volume available for cargo (See Appendix "B"). Using Curve Sheet"O""P" &"Q" together it is possible to compare the three classes of ships to obtain ship expense plus fixed charge cost per revenue ton carried. If, for example, we wish to find the relative cost per revenue ton for a voyage distance of 20,000 miles, we procede as follows:

Voyage distance 20,000 miles, ship 100% capacity
(Full and Down)

1. **From Curve Sheet** "O". The maximum sea time factors are: C2-74.5%, C3-67%, Mariner 67.5%.

2. **From Curve Sheet** "P", the maximum revenue tons per year are: C2-88 x 10^3, C3-108 x 10^3, Mariner - 150 x 10^3.

3. **From Curve Sheet** "Q", the cost per revenue ton, based on ship expense plus fixed charges only, is as follows: C2- $4.8/ton, C3 - $4.17/ton, Mariner - $4.50/ton.

The cost per revenue ton curves shown on Curve Sheet "R" have been calculated to show the results of using Curve Sheets "O", "P" and "Q" and shows the cost (ship expense and fixed charges) per revenue ton at the maximum available sea time factor plotted against round trip voyage distance for the C2, C3 and the Mariner Ship. The cost per deadweight ton (on the same basis as above) and the actual cost per deadweight ton based on M.A. information has been added for comparison purposes. The cost per revenue ton is a better comparison for mixed dry cargo ships as they have been designed to carry a predetermined mixture of weight and measurement (cubic) cargo and therefore the earning capacity is related to revenue tons rather than deadweight tons.

The curves showing cost per revenue ton are based on the standard C2, C3 and Mariner ships. Many of the C2 and C3 ships have been altered as noted under the section on deadweight and cubic capacity. The effect of the addition of additional deep tanks is to lower the revenue tons carried and therefore the cost per revenue ton is raised. Assuming that the additional deep tanks are not added in the largest hold (No. 3 for either the C2 or the C3 ship) the maximum available sea time factor will be the same. This results in the same cost per voyage. The bale cubic capacity of the ship reduces by the volume of the additional deep tanks while the magnitude of the decrease in the deadweight available for cargo depends on the method of bunkering. The assumption has been made that the ship loads fuel oil for voyage requirements up to the bunker capacity when leaving the first U. S. port, and any additional oil needed for the return passage is loaded in a foreign port. The C3 Ships have had the greatest additional deep tank capacity installed and this effect is noted on Curve Sheet "R" for two mileages, 20,000 and 30,000 miles. The result of the additional deep tank capacity (original deep tank fuel oil capacity - 112 tons; additional deep tank fuel oil capacity - 1829 tons; original fuel oil capacity - 1625 tons;

final fuel oil capacity - 3454 tons) when operating at either a 20,000 or a 30,000 mile voyage distance is to make the C3 ship still have the lowest cost per revenue ton although the difference between the C3 Ship and the Mariner Ship has been sharply reduced.

The lower cost per revenue ton for the C3 ship can be attributed to the slower speed and a subsequent reduction in the cost of the fuel oil. The other expenses are also lower than those for a Mariner Ship and the larger cargo capacity of the Mariner Ship is not great enough to overcome the higher cost.

The lower cost per deadweight ton for the C2 ship as against the C3 ship for both the 5,000 and 10,000 mile round trip voyages is due to the longer port time required by the C3 ship. The time required in port, loading or unloading revenue tons, is developed in Appendix "D" and is assumed to be the same when the cargo is all on a deadweight basis. At approximately a 14,000 mile voyage distance, the C3 curve crosses the C2 ship curve and for round trip voyage distances over 14,000 miles the C3 ship has the lowest cost per deadweight ton.

Curve Sheet "S" uses the same data as was used in determining the curves on Curve Sheet "R" but have been plotted on cost (ship expense and fixed charges) per ton (revenue and deadweight)-mile at the maximum available sea time factor versus round trip voyage distance basis. The relative positions of the ships remains unchanged.

The example shown above assumes that the availability of cargo is unlimited, which is unrealistic. Usually, available tonnage is relatively fixed and fleet size is varied according to speed of the various types of ships because the number of voyages per year for any particular trade route is set, primarily, in relation to the speed of the slowest ship. It is this factor that puts the Mariner ship, in particular, at a disadvantage. The operator, when considering the Mariner Ship, assumes that the number of sailings per year will be the same as for the smaller ship and computes the fleet size on the basis of the difference in speed of the two vessels. However, this is only half the story because with a Mariner ship the tonnage (weight and space) available for cargo has increased markedly. For this reason the number of ships required by a tonnage factor is less than the number of ships required by the speed factor. This is one reason why Mariner ships now operate at less than full cargos.

Using tonnage as the basic factor, the C3 ship has the cheapest ship expense plus fixed charge cost per revenue ton carried.

The cost (ship and fixed charge expense) per revenue ton was computed for the Mariner ship operating at 21, 20, 19, 18, 17 and 16 knots. The cost per revenue ton is lowest at the 20 knot speed. The various costs and tonnage figures computed for the Mariner ship and appearing on Curve Sheets "A" through "S", the data sheets under the Appendices and the various Tables use a Mariner ship speed of 20 knots.

On Curve Sheets "C" and "D", voyage expenses were included to show the theoretical effect of these expenses and are explained in Appendix "C". For the balance of the Curve Sheets "E" through "S" voyage expenses (stevedoring expense and port charges) have been omitted. Stevedoring expense is the same for all ships being on a cost per ton basis and, therefore, if included, will increase the ordinate of all curves using costs per ton in equal amounts. Port charges have been omitted because only two ports were assumed and therefore the port charge per revenue ton will not noticeably effect the results.

Conclusions

The conclusions reached are summarized below:

1. Only the Mariner ship, due to its large fuel oil cost per year, appears to offer a high enough permissible investment to be attractive for an atomic plant.

2. Only the Mariner has the speed and defense features necessary to be attractive to the Department of Defense.

3. The break-even distance on a round-trip voyage basis is comparitively short and the maximum deadweight and cubic gain of the nuclear ship is very substantial with the Mariner ship having the maximum overall gain.

4. The C3 ship gives the lowest cost per revenue ton (ship expense and fixed charge basis).

5. The C3 ship pays a severe penalty for its cargo hold subdivision. This results in a longer stay in port being 25 days as compared to 19 days for the C2 ship and 20 days for the Mariner ship. With a better cargo hold subdivision to reduce the port time, the cost per revenue ton would be considerably less.

6. There is an urgent need for a ship design in which speed of cargo handling (from the dock to the stowed position) is given prime importance. Cargo handling costs are too high, due primarily, to the handling of the cargo by hand too many times.

APPENDIX "A"

Theoretical Curve for Ship Expense per Mile

I Ship Expense per year

$$C_C = C_W + C_S + C_M + C_I + C_F$$

C_W = Wages and subsistence cost per year which are considered to be the same in port and at sea.
C_S = Stores, Supplies and Equipment cost per year.
C_M = Maintenance and Repair Cost per year.
C_I = Insurance cost per year.
C_F = Fuel Oil cost per year.

(a) Values for each of the costs are given in Table III.

(b) The port time varies slightly with the longer voyage but has been held constant in this study. The values used correspond to the time for loading and unloading the largest hatch of the ship when working 16 hours per day.

(c) The number of miles travelled per year is

$$MN = \frac{350}{\left(\frac{D_P}{M} + \frac{1}{24V}\right)}$$

D_P = Days in port per voyage
V = Rated speed of vessel
M = Miles travelled per round trip
N = Number of voyages per year

II Ship Expense per Mile:

$$\frac{C_C}{MN} = \frac{C_W + C_S + C_M + C_I}{\;}\left(\frac{D_P}{M} + \frac{\;}{24V}\right) + \frac{C_F}{MN}$$

$$C_F = N\left(c_P + c_S D_S\right) + D_U c_P$$

c_P = Cost of Fuel Oil per day in port
c_S = Cost of Fuel Oil per day at sea
D_U = Days that ship is unavailable for cargo

$$\frac{C_c}{MN} = \frac{(C_W+C_S+C_m+C_I+D_U /C_P)D_P}{350\,M} + \frac{(C_W+C_S+C_M+C_I+D_U /C_P)}{350 \times 24V} + \frac{/C_P D_P + /C_S D_S}{M}$$

$$D_S = \frac{M}{24V}$$

$$\frac{C_S}{MN} = \frac{(C_W+C_S+C_M+C_I+D_U /C_P+350 /C_P)D_P}{350M} + \frac{(C_W+C_M+C_S+C_I+D_U /C_P)}{350 \times 24V} + \frac{/C_S D_S}{M}$$

$$\frac{C_c}{MN} = \frac{(C_W+C_S+C_M+C_I+D_U /C_P+350 /C_P)D_P}{350M} + \frac{(C_W+C_S+C_M+C_I+D_U /C_P)}{350 \times 24v} + \frac{/C_S}{24v}$$

2. $$A = \frac{C_c}{MN} = \frac{(C_W+C_S+C_M+C_I+D_U /C_P+350 /C_P)D_P}{350\,M} + \frac{C_W+C_S+C_M+C_I+D_U /C_P+350 /C_S}{350 \times 24V}$$

Denoting all constant terms for any one ship by K values the equation becomes

2A. $$A = \frac{C_c}{MN} = \frac{K_1}{M} + K_2$$

Therefore the cost per mile should be a hyperbolic curve approaching a limit equal to K2 as M approaches infinity.

Appendix "A" Data Sheet

The table below shows the values used in determining the theoretical curve shown on ship expenses per mile plotted against voyage distance in miles.

		C2	C3	Mariner
$C_w/1000$	\$/yr.	389.0	406.0	472.5
$C_s/1000$	\$/yr.	45.6	47.4	63.9
$C_m/1000$	\$/yr.	73.0	78.5	63.9
$C_I/1000$	\$/yr.	73.0	76.6	150.0
$\hat{C}_p$	\$/day	63.0	74.0	106.0
$\hat{C}_s$	\$/day	480.0	640.0	1225.0
D_p	days	19.0	25.0	20.0
D_u	days	15	15.0	15.0
V	Knots	15.0	16.5	20.0
K_1		32,800	45,300	45,000
K_2		5.95	6.01	7.02

Equation No. 2A $A = \frac{K_1}{M} + K_2$

Ship Expense Per Mile	A	A	A
5,000 Miles	12.51	15.07	16.02
10,000 Miles	9.23	10.54	11.52
20,000 Miles	7.59	8.28	9.27
30,000 Miles	7.04	7.52	8.52

APPENDIX "B"

Theoretical Curve for Ship Expense per ton

I Ship Expense per year

1. $C_c = C_\omega + C_s + C_m + C_I + C_F$

II Deadweight available for cargo per voyage

3. $\Delta_c = 2\Delta_\omega - \Delta_f - \Delta_\omega - \Delta_s - \Delta_m$

4. $B = \Delta_c = 2\Delta_\omega - 1.5(D_s\Delta_s + D_p\Delta_p)1.2 - 1.5\,D_T(S_\Delta + W_\Delta) - 2M_\Delta$

Δ_c = Cargo carried per voyage - tons
Δ_ω = Ships deadweight - tons
D_s = Days at Sea per voyage
D_p = Days in Port per voyage
D_T = Ds + Dp = Total days per voyage
Δ_s = Fuel Oil consumption per day at sea - tons/D
Δ_p = Fuel Oil consumption per day in port - tons/D
S_Δ = Consumable Stores used per day - tons/D
W_Δ = Fresh Water Consumed per day - tons/D
M_Δ = Crew and effects - tons

All values are constant except Ds

Equation No. 4. is valid for any voyage distance in which the fuel oil consumed and the fresh water consumed does not exceed the fuel oil and fresh water tank capacity. Beyond this refueling and the filling of water tanks must be factored in.

III Revenue (Stevedore) tons

Equation 4 gives the deadweight tons available for cargo. However, for any ship to carry her maximum load to achieve the greatest possible profit return, the cargo carried should be of a blend of commodities of various densities appropriate to load the ship both full and down simultaneously. With such a blend of commodities, the ship may carry a cargo for which the measure in revenue (stevedore) tons exceeds the ships capacity as measured either in weight tons or measurement tons. The revenue tons which can be carried is a function of the ratio (λ) of the available bale cubic volume (C_B) to the available cargo deadweight (Δ_c) in tons.

$$C_B = A_w + \%_w \Delta_c + B_v (1 - \%_w) \Delta_c$$

$$\Delta_c = \Delta_w + \Delta_v = \%_w \Delta_c + (1 - \%_w) \Delta_c$$

A_w = Average cubic feet per ton of the cargo paid for on a weight basis which is assumed to be 25 cu. ft. per ton.

B_v = Average cubic feet per ton of all volume cargo paid for on a measurement basis which is assumed to be 100 cu. ft. per ton.

$\%_w$ = Percent of deadweight cargo which is paid for on a weight basis.

Δ_w = Weight of weight cargo - tons

Δ_v = Weight of volume cargo - tons

The assumed figures for Aw + Bv are the result of the study of stowage factor tables.

$$\lambda = \frac{C_B}{\Delta_c} = A_w \times \%_w + B_v (1 - \%_w)$$

Δ_c varies with the length of the voyage as given in equation 4.

$$\%_w = \frac{\frac{C_B}{\Delta_c} - B_v}{A_w - B_v}$$

Revenue tons $\Delta_R = \%_w \Delta_c + (1 - \%_w) \Delta_c \left(\frac{B_v}{40}\right)$

The factor $B_v/40$ converts the volume tons to equivalent measurement tons for revenue purposes.

$$\Delta_R = \left(\frac{\frac{C_B}{\Delta_c} - B_v}{A_w - B_v}\right) \Delta_c + \left[1 - \left(\frac{\frac{C_B}{\Delta_c} - B_v}{A_w - B_v}\right)\right] \Delta_c \frac{B_v}{40}$$

5. $$\Delta_R = \left(\frac{C_B - B_v \Delta_c}{A_w - B_v}\right)\left(1 - \frac{B_v}{40}\right) + \frac{\Delta_c B_v}{40}$$

Δ_R = Revenue tons per voyage - tons

C_B = Twice the Bale Cubic of the Ship - cu. ft.

Δ_c = Deadweight available for cargo per voyage - tons Δ_c varies with the voyage distance and percent of time spent at sea as shown in equation 4.

A_w = Assumed stowage factor for weight cargo - 25 cu. ft. per ton

B_v = Assumed stowage factor for measurement cargo - 100 cu. ft. per ton

Equation No. 5 can be rewritten using K values for those values constant for any one ship.

$$\Delta_R = \left(\frac{K_1 - K_2 \Delta_c}{K_3}\right)(1 - K_4) + K_4 \Delta_c$$

$$K_5 = 1 - K_4$$

$$\Delta_R = \frac{K_1K_5}{K_3} - \frac{K_2K_5}{K_3}\Delta_c + K_4\Delta_c$$

$$= \frac{K_1K_5}{K_3} + \left(K_4 - \frac{K_2K_5}{K_3}\right)\Delta_c$$

$$K_6 = \frac{K_1K_5}{K_3} = \frac{C_B\left(1-\frac{B_V}{40}\right)}{A_w - B_V} = \frac{C_B}{50}$$

$$K_7 = K_4 - \frac{K_2K_5}{K_3} = \left[\frac{B_V}{40} - \frac{B_V\left(1-\frac{B_V}{40}\right)}{A_w - B_V}\right]\Delta_c = 0.5\Delta_c$$

5A $\Delta_R = K_6 + K_7\Delta_c = \frac{C_B}{50} + 0.5\Delta_c$

IV Ship Expense per Deadweight Ton

$$\frac{C_c}{N\Delta_c} = \frac{C_W + C_S + C_M + C_I + C_F}{N\left[2\Delta_w - 1.5(D_S\Delta_S + D_P\Delta_P)1.2 - 1.5\,D_T(S_\Delta + W_\Delta) - 2M_\Delta\right]}$$

Only variables are C_F, N & D_S

$D_S = \frac{M}{24V}$

$C_F = N(\not{C}_P D_P + \not{C}_S D_S) + D_U\not{C}_P = N\left(\not{C}_P D_P + \not{C}_S\frac{M}{24V}\right) + D_U\not{C}_P$

$\not{C}_P$ = Cost of Fuel Oil consumed in port per day
$\not{C}_S$ = Cost of Fuel Oil consumed at sea per day
D_P = Days in port per voyage
D_S = Days at sea per voyage
N = Number of voyages per year
M = Miles per voyage
D_U = Days that ship is unabailable for cargo

$$\frac{C_c}{N\Delta_c} = \frac{C_W + C_S + C_M + C_I + D_U\not{C}_P + N\left(\not{C}_P D_P + \not{C}_S\frac{M}{24V}\right)}{N\left[2\Delta_w - 1.5\left(\frac{M}{24V}\Delta_S + D_P\Delta_P\right)1.2 - 1.5\left(D_P + \frac{M}{24V}\right)(S_\Delta + W_\Delta) - 2M_\Delta\right]}$$

$$N = \frac{350}{D_S + D_P} = \frac{350}{\frac{M}{24V} + D_P}$$

$$\frac{C_c}{N\Delta_c} = \frac{\left(D_P + \frac{M}{24V}\right)\left(\frac{C_W + C_S + C_M + C_I + D_U\not{C}_P}{350}\right) + \not{C}_P D_P + \not{C}_S\frac{M}{24V}}{2\Delta_w - 1.5\left(\frac{M}{24V}\Delta_S + D_P\Delta_P\right)1.2 - 1.5\left(D_P + \frac{M}{24V}\right)(S_\Delta + W_\Delta) - 2M_\Delta}$$

$$6.\ C = \frac{C_c}{N\Delta_c} = \frac{\frac{(C_W + C_S + C_M + C_I + D_U\not{C}_P + 350\not{C}_P)D_P}{350} + \frac{(C_W + C_S + C_M + C_I + D_U\not{C}_P + 350\not{C}_S)M}{350 \times 24V}}{\Delta_c}$$

Denoting all constant terms for any one ship by K values the quation becomes

6A $$C = \frac{C_c}{N\Delta_c} = \frac{K_1 + K_2 M}{\Delta_c}$$

V Ship expense per Revenue Ton

$$\frac{C_c}{N\Delta_R} = \frac{C_W + C_S + C_M + C_I + C_F}{N\left[\left(\frac{C_B - B_V\Delta_C}{A_W - B_V}\right)\left(1 - \frac{B_V}{40}\right) + \frac{B_V}{40}\Delta_C\right]}$$

Only variables are C_F, Δ_C & N

$$C_F = N\left(\not{C}_P D_P + \not{C}_S D_S\right) + D_U \not{C}_P = N\left(\not{C}_P D_P + \not{C}_S \frac{M}{24V}\right) + D_U \not{C}_P$$

$$\frac{C_c}{N\Delta} = \frac{C_W + C_S + C_M + C_I + N\left(\not{C}_P D_P + \not{C}_S \frac{M}{24V}\right) + D_U \not{C}_P}{N\left[\left(\frac{C_B - B_V\Delta_C}{A_W - B_V}\right)\left(1 - \frac{B_V}{40}\right) + \frac{B_V}{40}\Delta_C\right]}$$

$$\frac{C_c}{N\Delta_R} = \frac{\left(D_P + \frac{M}{24V}\right)\left(\frac{C_W + C_S + C_M + C_I + D_U \not{C}_P}{350}\right) + \not{C}_P D_P + \not{C}_S \frac{M}{24V}}{\left(\frac{C_B - B_V\Delta_C}{A_W - B_V}\right)\left(1 - \frac{B_V}{40}\right) + \frac{B_V}{40}\Delta_C}$$

7. $$D = \frac{C_c}{N\Delta_R} = \frac{\left(\frac{C_W + C_S + C_M + C_I + D_U \not{C}_P + 350 \not{C}_P}{350}\right) D_P + \left(\frac{C_W + C_S + C_M + C_I + D_U \not{C}_P + 350 \not{C}_S}{350 \times 24V}\right) M}{\left(\frac{C_B - B_V\Delta_C}{A_W - B_V}\right)\left(1 - \frac{B_V}{40}\right) + \frac{B_V}{40}\Delta_C}$$

Denoting all constant terms for any one ship by K values, the equation becomes.

$$\left(\frac{C_W + C_S + C_M + C_I + D_U \not{C}_P + 350 \not{C}_P}{350}\right) D_P = K_1$$

$$\left(\frac{C_W + C_S + C_M + C_I + D_U \not{C}_P + 350 \not{C}_S}{350 \times 24V}\right) M = K_2 M$$

$$\left(\frac{C_B - B_V\Delta_C}{A_W - B_V}\right)\left(1 - \frac{B_V}{40}\right) + \frac{B_V}{40}\Delta_C = K_6 + K_7\Delta_C$$

7A $$D = \frac{C_c}{N\Delta_R} = \frac{K_1 + K_2 M}{K_6 + K_7\Delta_C}$$

Appendix "B" Data Sheet

The table below shows the valves used in determining the theoretical curves shown as ship expense per deadweight ton and per revenue ton. These curves are plotted on Curve Sheet B.

			C2	C3	Mariner
Δ_w	Ship Deadweight	Tons	10,822	12,258	13,409
Δ_s	F.O. Consumption/Sea Day	Tons	32.8	43.6	84.0
Δ_p	F.O. Consumption/Port Day	Tons	4.32	5.07	7.27
D_p	Days in Port/100% Capacity		19.0	25.0	20.0
D_s	Days at Sea - 5,000 Miles		13.88	12.62	10.41
	10,000 Miles		27.76	25.24	20.82
	20,000 Miles		55.52	50.48	41.64
	30,000 Miles		83.3	75.72	62.46
S_Δ	Stores Consumption	Tons/Day	1.5	1.8	2.0
W_Δ	Water Consumption	Tons/Day	6 up to 326	8 up to 407	10 up to 257
M_Δ	Crew and Effects	Tons	25	30	35
Δ_c	Deadweight available for cargo using equation				
	No. 4 - 5,000 miles		20,258	22,719	24,565
	10,000 miles		19,378	21,693	22,961
	20,000 miles		18,216	20,812	20,315
	30,000 miles		17,603	20,527	19,199
$C_w/1000$		\$/yr.	389.0	406.0	472.5
$C_s/1000$		\$/yr.	45.6	47.4	63.9
$C_m/1000$		\$/yr.	73.0	78.5	63.9
$C_I/1000$		\$/yr.	73.0	76.6	150.0
τ_p		\$/day	63.0	74.0	106.0
τ_s		\$/day	480.0	640.0	1225.0
D_v		Days	15.0	15.0	15.0
V		Knots	15.0	16.5	20.0
C_B	(2 x Ship Bale Cubic Cap.)	cu. ft.	1085.6×10^3	1473.6×10^3	1534.0×10^3
B_v			100	100	100
A_w			25	25	25

Appendix "B" (continued) Data Sheet

	C2		C3		Mariner	
Equation No.	(6A)	(7A)	(6A)	(7A)	(6A)	(7A)
K Values						
K1	32,800	32,800	45,400	45,400	45,100	45,100
K2	5.94	5.94	6.01	6.01	7.01	7.01
K6		21,710		29,470		30,680
K7		0.5		0.5		0.5
Ans.						
5,000 Miles	3.09	1.96	3.32	1.85	3.26	1.87
10,000 Miles	4.76	2.94	4.86	2.62	5.11	2.73
20,000 Miles	8.32	4.92	7.96	4.15	9.12	4.54
30,000 Miles	11.99	6.92	11.00	5.67	13.30	6.34

Appendix "C"

Theoretical Curves for Total Ship Expenses per Mile or per Ton (Deadweight and Revenue)

The basic data for these curves was developed in Appendices "A" and "B". Only the equations will be given in this section together with an explanation of any new symbols or constants.

I Total Expenses per year

Total Expenses = Ship Expenses + Voyage Expenses + Fixed Charges

$$C_T = (C_W + C_S + C_M + C_I + C_F) + C_V + C_o$$

Voyage Expense = Cargo Expense + Ship Handling Expense

$$C_V = C_\Delta + C_H$$

$$= N(c_c\Delta_c) + N(K + c_A\Delta_c)$$

$K + c_A\Delta = C_H$ for a full and down ship

$$C_V = N\Delta(C_e + K/\Delta + c_A)$$

Δ_c = Cargo tons per Voyage

c_c = Cost of handling a ton of cargo either in or out of ship

K = Minimum cost of Port Charges per voyage

c_A = Cost per ton for Port Charges per voyage above the minimum

c_H = Port Charges per voyage for a full and down ship

C_o = Fixed charges including depreciation, overhead and interest for a new ship.

8. $C_T = C_W + C_S + C_M + C_I + C_o + D_U C_P + N(c_P D_P + c_S \frac{M}{24V} + N\Delta_c(c_e + \frac{K}{\Delta_c} + c_A)$

8A. $C_T = C_W + C_S + C_M + C_I + C_o + D_U C_P + N(c_P D_P + c_S \frac{M}{24V}) + N c_H + N c_c \Delta_c$

Equation 8A will be used as theoretical curve assumes a full and down ship.

II Total expenses per mile

$$E = \frac{C_I}{NM} = \frac{C_W + C_S + C_M + C_I + C_o + D_U C_p + N(c_p D_p + c_s D_s) + N\Delta_c c_o + N c_H}{NM}$$

9. $E = \frac{C_T}{NM} = \left(\frac{C_W + C_S + C_M + C_I + C_o + D_U C_p + 350 c_p}{350M}\right) D_p + \left(\frac{C_W + C_S + C_M + C_I + C_o + D_U C_p + 350 c_s}{350 \times 24V}\right) + \frac{\Delta c_c}{M} + \frac{C_H}{M}$

All terms are constant except M & Δ . Denoting all constant terms by K Values the equation becomes

9A. $$E = \frac{C_T}{NM} = \frac{K_1'}{M} + K_2' + \frac{K_3'}{M} + \frac{\Delta_c K_4'}{M}$$

As Δ_c is relatively constant the cost per mile should approximate a hyperbolic curve approaching a limit equal to K_2' as M approaches infinity.

III Total Expenses per Deadweight Ton

$$F = \frac{C_T}{N\Delta_c} = \frac{C_w + C_s + C_I + C_o + D_u /C_P + N(/C_P D_P + /C_S D_S) + N\Delta_c /C_c + N /C_H}{N\Delta_c}$$

$$F = \frac{C_T}{N\Delta_c} = \frac{\left(D_P + \frac{M}{24V}\right)\left(\frac{C_w + C_s + C_M + C_I + C_o + D_u /C_P}{350}\right) + /C_P D_P + /C_S \frac{M}{24V} + /C_H}{\Delta_c} + /C_c$$

10. $$= \frac{\left(\frac{C_w + C_s + C_M + C_I + C_o + D_u /C_P + 350 /C_P}{350}\right) D_P + \left(\frac{C_w + C_s + C_M + C_I + C_o + D_u /C_P + 350 /C_S}{350 \times 24V}\right) M + /C_H}{\Delta_c} + /C_c$$

Denoting all constant terms for any one ship by <u>K</u> the equation becomes

10A $$F = \frac{C_T}{N\Delta_c} = \frac{K_1' + K_2 M + K_3'}{\Delta_c} + K_4'$$

IV Total Expense per Revenue Ton

$$G = \frac{C_T}{N\Delta_R} = \frac{C_w + C_s + C_M + C_I + C_o + D_u /C_P + N\left(/C_P D_P + \frac{M}{24V} /C_S\right) + N\Delta_R /C_c + N /C_H}{\Delta_R}$$

$$G = \frac{C_T}{N\Delta_R} = \frac{\left(D_P + \frac{M}{24V}\right)\left(\frac{C_w + C_s + C_M + C_I + C_o + D_u \cdot C_P}{350}\right) + /C_P D_P + /C_S \frac{M}{24V} + /C_H}{\Delta_R} + /C_c$$

11 $$= \frac{\left(\frac{C_w + C_s + C_M + C_I + C_o + D_u /C_P + 350 /C_P}{350}\right) D_P + \left(\frac{C_w + C_s + C_M + C_I + D_u /C_P + 350 /C_S}{350 \times 24V}\right) M + /C_H}{\left(\frac{C_B - B_V \Delta_c}{A_W - B_V}\right)\left(1 - \frac{B_V}{40}\right) + \frac{B_V}{40}\Delta_c} + /C_c$$

Denoting all constant terms for any one ship by <u>K</u> values the equation becomes

11A $$G = \frac{C_T}{N\Delta_R} = \frac{K_1' + K_2' M + K_3'}{K_6 + K_7 \Delta_c} + K_4'$$

Appendix "C" Data Sheet

The table below shows the values used in determining the theoretical curves shown as total ship operating cost per mile, per deadweight cargo tons and per revenue tons plotted against voyage distance in miles. The values for Δ_C and Δ_R were taken from Appendix "B".

		C2		C3		Mariner	
		Δ_c	Δ_R	Δ_c	Δ_R	Δ_c	Δ_R
Δ - 5,000 Miles	Tons	20,258	31,800	22,719	40,700	24,565	42,900
10,000 Miles	Tons	19,378	31,400	21,693	40,400	22,961	42,200
20,000 Miles	Tons	18,216	30,800	20,812	39,880	20,315	40,838
30,000 Miles	Tons	17,603	30,500	20,527	39,720	19,199	40,277
C_W/1000	\$/yr.	389.0		406.0		472.5	
C_s/1000	\$/yr.	45.6		47.4		63.9	
C_M/1000	\$/yr.	73.0		78.5		63.9	
C_I/1000	\$/yr.	73.0		76.4		150.0	
C_o/1000 (new ship)	\$/yr.	233.2		269.0		375.1	
$\mathcal{C}_r$	\$/Day	63.0		74.0		106.0	
$\mathcal{C}_s$	\$/Day	480.0		640.0		1225.0	
D_p	Days	19.0		25.0		20.0	
D_u	Days	15.0		15.0		15.0	
V		15.0		16.5		20.0	
$\mathcal{C}_c$ in and out of ship	\$/ton	10.0		10.0		10.0	
$\mathcal{C}_H$ Port Charges	\$/voyage	3940.0		4712.0		4116.0	
C_B(Ship B.C. Cap. x 2)	cu.ft.	1,085,648		1,473,700		1,533,954	
B_v	cu.ft.	100		100		100	
A_w	cu.ft.	25		25		25	

Appendix "C"

Data Sheet

	C2			C3			Mariner		
Equation No.	9A	10A	11A	9A	10A	11A	9A	10A	11A
K Values									
K1	45,400	45,400	45,400	64,600	64,600	45,400	66,400	66,400	45,400
K2	7.80	7.80	7.80	7.96	7.96	7.96	9.26	9.26	9.26
K3	3940.0	3940	3940.0	4712.0	4712.0	4712.0	4116.0	4116.0	4116.0
K4	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
K6			21,710			29,470			30,680
K7			0.5			0.5			0.5
Ans.	$\$/M$	$\$/\Delta_c$	$\$/\Delta_R$	$\$/M$	$\$/\Delta_c$	$\$/\Delta_R$	$\$/M$	$\$/\Delta_c$	$\$/\Delta_R$
5,000 Miles	81.27	14.36	12.78	103.22	14.8	12.20	109.16	14.76	12.20
10,000 Miles	44.13	16.57	14.06	55.29	16.87	13.22	58.51	17.1	13.37
20,000 Miles	25.67	21.27	16.66	31.37	20.98	15.25	33.21	22.59	15.75
30,000 Miles	19.61	26.10	19.29	23.51	25.01	17.27	25.04	28.14	18.13

Appendix C (continued) Data Sheet

Cargo Costs & Port Charges

	C2	C3	Mariner
Cargo Costs per ton Δ_c or Δ_R (3.23 x 2 plus overtime allowance)	10.0	10.0	10.0
Port Charges per Voyage (F & D Ship in & out)			
Items			
Pilotage	$ 177x4= 708	$ 184x4= 736	$ 190x4= 760
Tug	150x4= 600	150x4= 600	150x4= 600
Wharfage	237x2= 474	283x2= 566	246x2= 492
Lines	49.5x2= 98	49.5x2= 98	49.5x2= 98
Watchforce	349x2= 698	459x2= 918	366x2= 732
Clerks 3 due to overtime	454x3= 1362	598x3= 1794	478x3= 1434
Total Ch per voyage	$ 3940	$ 4712	$ 4116
Days in Port/voy.	19	25	20

Appendix "D"

Maximum Available Time at Sea Factor - 100% Cargo Capacity

I Revenue Tons per Voyage

The revenue tons per voyage were computed using Equations No. 2A in Appendix "A" and Equation No. "5A" in Appendix "B". They were computed for the time at sea factors of 80, 70, 60, 50 and 40 percent at 5,000, 10,000, 20,000 and 30,000 mile round trip voyage distances. The average revenue tons was obtained for each voyage distance and this value was used in obtaining the minimum port time.

II Port Time

The port time is a function of the revenue tons carried, the division of the revenue tons into the various holds, the speed of loading and unloading, the time to enter and leave port and the time to rig and stow the cargo gear. The assumption is made that the cargo carried is divided into the various holds in proportion to the bale cubic capacity of the various holds. The port time can be expressed by the following formula:

12. $$D_P = 2\left[\frac{\Delta_R \times 2\mathcal{C}_B}{C_B \times S_H \times H_D} + \frac{T_D}{24} + \frac{T_R}{24}\right]$$

Δ_R = Average revenue tons
$\mathcal{C}_B$ = Bale cubic capacity of the largest hold -cu.ft.
C_B = Twice the bale cubic capacity of the ship -cu.ft.
S_H = Loading or unloading rate - tons per hour
H_D = Hours per day that the largest hold is worked- assumed to be 16 hours per day
T_D = Time in hours to move ship from pilot station to dock and dock to pilot station
T_R = Time in hours to rig and stow the cargo gear and prepare for sea

III Maximum Sea Time Factor

$$F_s = \frac{D_s}{D_s + D_P}$$

$$D_s = \frac{M}{24V}$$

D_P = Time in Port computed by equation No. 12.

13. $$F_s = \frac{\frac{M}{24V}}{\frac{M}{24V} + 2\left[\frac{\Delta_R + 2C_B}{C_B + S_H + H_D} + \frac{T_D}{24} + \frac{T_R}{24}\right]}$$

Denoting all constant terms for any one ship by K values the equation becomes.

13A. $$F_s = \frac{\frac{M}{K_1''}}{\frac{M}{K_1''} + K_2''\Delta_R + K_3'' + K_4'}$$

Appendix "D" Data Sheet

The table below shows the values used in determining the maximum available sea time factors for various voyage distances plotted against voyage round trip distance.

	C2	C3	Mariner
Arg. Revenue Tons-			
5,000 Miles			
10,000 Miles			
20,000 Miles			
30,000 Miles			
C_B - B.C. of Largest Hold	135,649	191,980	161,415
C_B - Twice Ship B.C. Capacity	1,085,648	1,473,700	1,533,954
S_H - Loading & Unloading Rate in tons per hour (1)	53.3	53.3	56
H_D - Hours worked per day	16	16	16
T_D - (assumed) hours	7	7	7
T_R - (assumed) hours	4	3	2
V - Ship Speed Knots	15.0	16.5	20.0
Equation 13A K Values			
K1"	360	396	480
K2"	5.87×10^{-4}	6.12×10^{-4}	4.71×10^{-4}
K3"	0.58	0.58	0.58
K4"	0.33	.25	.17
Minimum Port Time at 100% Cargo Capacity			
5,000 Miles	19.61	25.83	20.95
10,000 Miles	19.24	25.33	20.65
20,000 Miles	18.87	25.08	19.85
30,000 Miles	18.68	24.93	19.77
Maximum Available Sea Time Factor at 100% Cargo Capacity 5,000 Miles	41.40	32.80	33.3
10,000 Miles	58.95	49.00	50.3
20,000 Miles	74.75	66.70	67.7
30,000 Miles	81.70	75.30	76.1
Maximum Available Sea Time Factor at 60% Cargo Capacity 5,000 Miles	53.30	44.4	44.8
10,000 Miles	69.90	62.0	62.3
20,000 Miles	82.70	76.7	77.4
30,000 Miles	87.80	83.2	83.8

(1) Reference(d)

Table I

Utilization of Ships Calender Year 1953

			Deadweight Tonnage				Space (Cubic Feet)			
Trade Route	Co.	No. of Sail-ings	Avail-able (1000)	Utili-zed (1000)	Per-cent %	Avg/ Pass (1000)	Avail-able (1000)	Utili-zed (1000)	Per-cent %	Avg/ Pass (1000)
A-Round trip Mileage -		17,000								
Outbound	1	26	234	174	74	7	13,654	12,725	93**	489
	2	70	696	572	82	8	40,094	38,469	96**	550
	3	26	248	182	73	7	16,828	10,067	96**	618
Inbound	1	27	253	66	26	2	14,736	5,909	40	219
	2	73	783	99	13	1	40,816	6,818	17	93
	3	26	268	60	22	2	17,067	5,977	35	230
	4	11	116	53	46	5	6,303	3,299	52	299
B-Round trip Mileage -		20,000								
	5	24	195	97	50	4	14,101	7,017	50	292
	6	33	281	129	46	4	20,193	14,187	70	430
Inbound	5	26	257	249	97*	9.5	15,799	10,847	69	417
	6	33	336	329	98*	9.9	21,031	15,537	74	471
C-Round trip Mileage -		26,000								
Outbound	7	12	105	98	93*	8	6,672	6,610	99**	551
Inbound	7	12	107	58	54	4.8	6,686	2,681	40	223

* indicates full weight cargo
** indicates full cubic cargo

Table II

Time at Sea Factors

	Factor %		
Distance	C 2	C 3	C 4
15,000		51.0	
16,000	63.3	58.8	48.8
18,000	48.5		
19,000	54.6	55.4	
20,000	54.2	55.2	
25,000		50.1	
27,000	58.8		
30,000	67.2		

Table III

Average Cost Data - Dollars per Day

Ship	C2-S-AJ1		C3-S-A2		Mariner	
Speed K	15		16.5		20	
Dwt. Tons	10,822		12,258		13,409	
Ship Expense*	Sea	Port	Sea	Port	Sea	Port
Wages, Taxes & Fringe Benefits	960.0	960.0	1,010.0	1,010.0	1197.0	1197.0
Subsistence	105.0	126.0	110.0	132.0	99.0	116.0
Stores, Supplies & Equipment	125.0	125.0	130.0	130.0	175.0	175.0
Fuel (Rated Speed-100% load)**	480.0	63.0	640.0	74.0	1225.0	106.0
Maintenance & Repair	200.0	200.0	215.0	215.0	175.0	175.0
P & l. Insurance	45.0	45.0	43.0	43.0	70.0	70.0
H & M Insurance (Assumed)	155.0	155.0	167.0	167.0	340.0	340.0
Misc. Ship Expense	0	0	0	0	0	0
Sub Total Cost Per Day	2070	1674.0	2315.0	1771.0	3277.0	2179.0

** Fuel Cost - $2.20 per barrel

* C2 and C3 Ship Expense reference (e)
Mariner Ship Expense reference (f)

Table III
(Continued)
Average Cost Data - Dollars per Day

Ship	C2-S-AJ1		C3-S-A2		Mariner	
Speed K	15		16.5		20	
Dwt. Tons	10,822		12,258		13,409	
Fixed Charges (New Ship)	Sea	Port	Sea	Port	Sea	Port
Interest on Mortgage	105.0	105.0	127.0	127.0	190.0	190.0
Depreciation	384.0	384.0	461.0	461.0	688.0	688.0
Overhead	150.0	150.0	150.0	150.0	150.0	150.0
Sub total cost per Day	639.0	639.0	738.0	738.0	1028.0	1028.0
Total Ship Expense and Fixed Charges Per Day	2709.0	2313.0	3053.0	2509.0	4305.0	3207.0

Table IV

Cost per year comparisons with a C2 Vessel (Ship and Fixed Charge Expenses)
At Various Time at Sea Factors

Time at Sea Factor	C2 Ship	C3 Ship		Mariner	
	$/yr.	$/yr.	Inc. %	$/yr.	Inc. %
80%	955,200	1,068,100	11.9	1,478,000	54.8
70%	941,300	1,048,900	11.4	1,439,600	53.0
60%	927,400	1,030,000	11.1	1,401,100	51.2
50%	913,600	1,011,000	10.9	1,362,700	49.2
40%	899,700	991,900	10.5	1,324,300	47.4

Table V

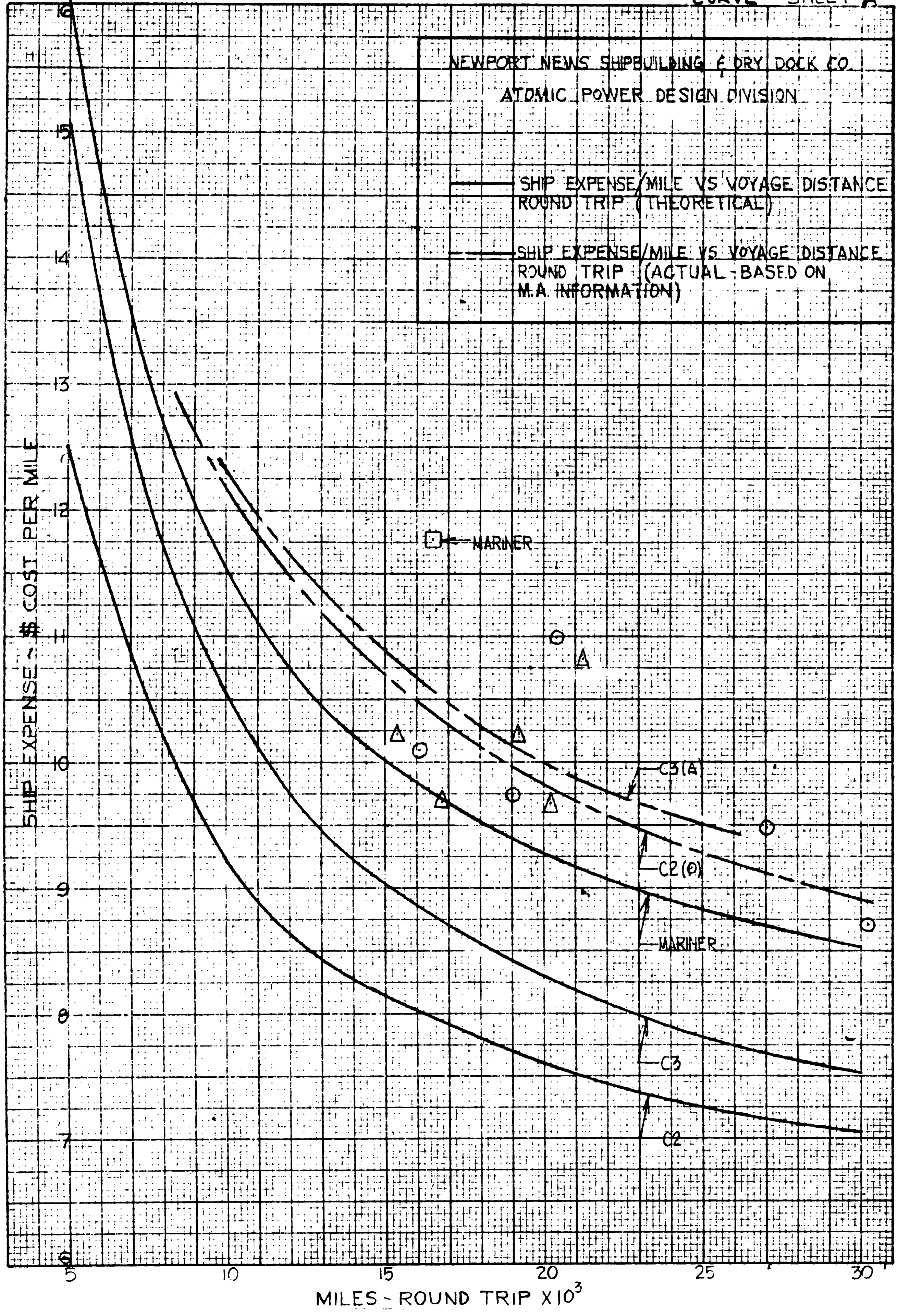
Cost per year comparisons with a C2 Vessel (Ship and Fixed Charge Expense) (100% Cargo Capacity)
At Various Distances - Maximum Sea Time Factors

	C2 Ship							
Miles	Time at Sea Factor*	$/yr.	Time at Sea Factor	$/yr.	Inc. %	Time at Sea Factor	$/yr.	Inc. %
5,000	41.4	902,000	32.3	978,000	8.5	33.3	1,297,000	43.8
10,000	58.9	926,000	49.6	1,011,000	9.2	50.4	1,363,000	47.1
20,000	74.7	948,000	67.2	1,044,000	10.1	67.6	1,430,000	50.8
30,000	81.7	958,000	75.6	1,061,000	10.8	76.1	1,463,000	52.8

* All time at sea factors taken from maximum available sea time factor at 100% cargo capacity for each ship (Curve 0)

LIST OF CURVE SHEETS

CURVE SHEET "A"



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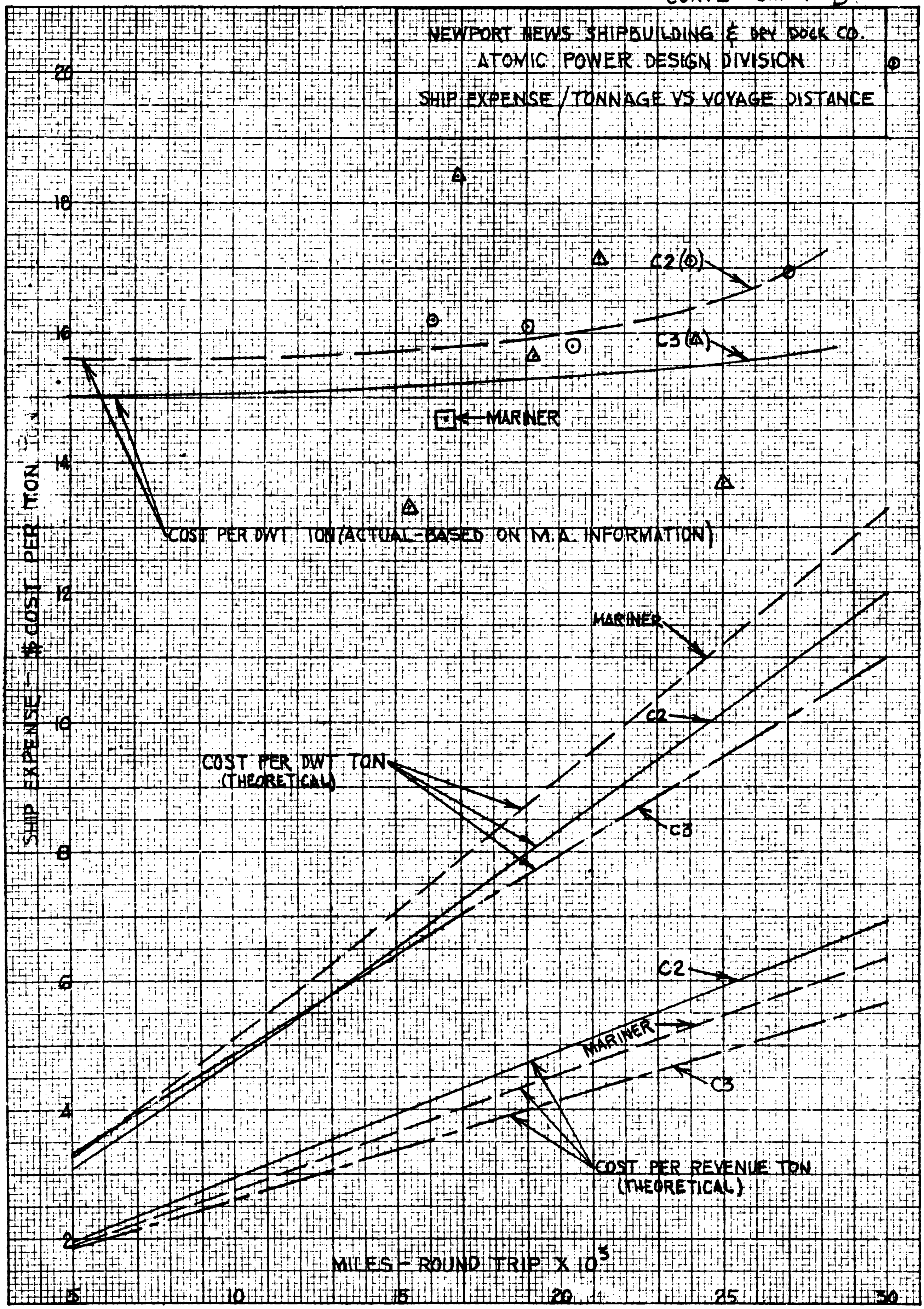

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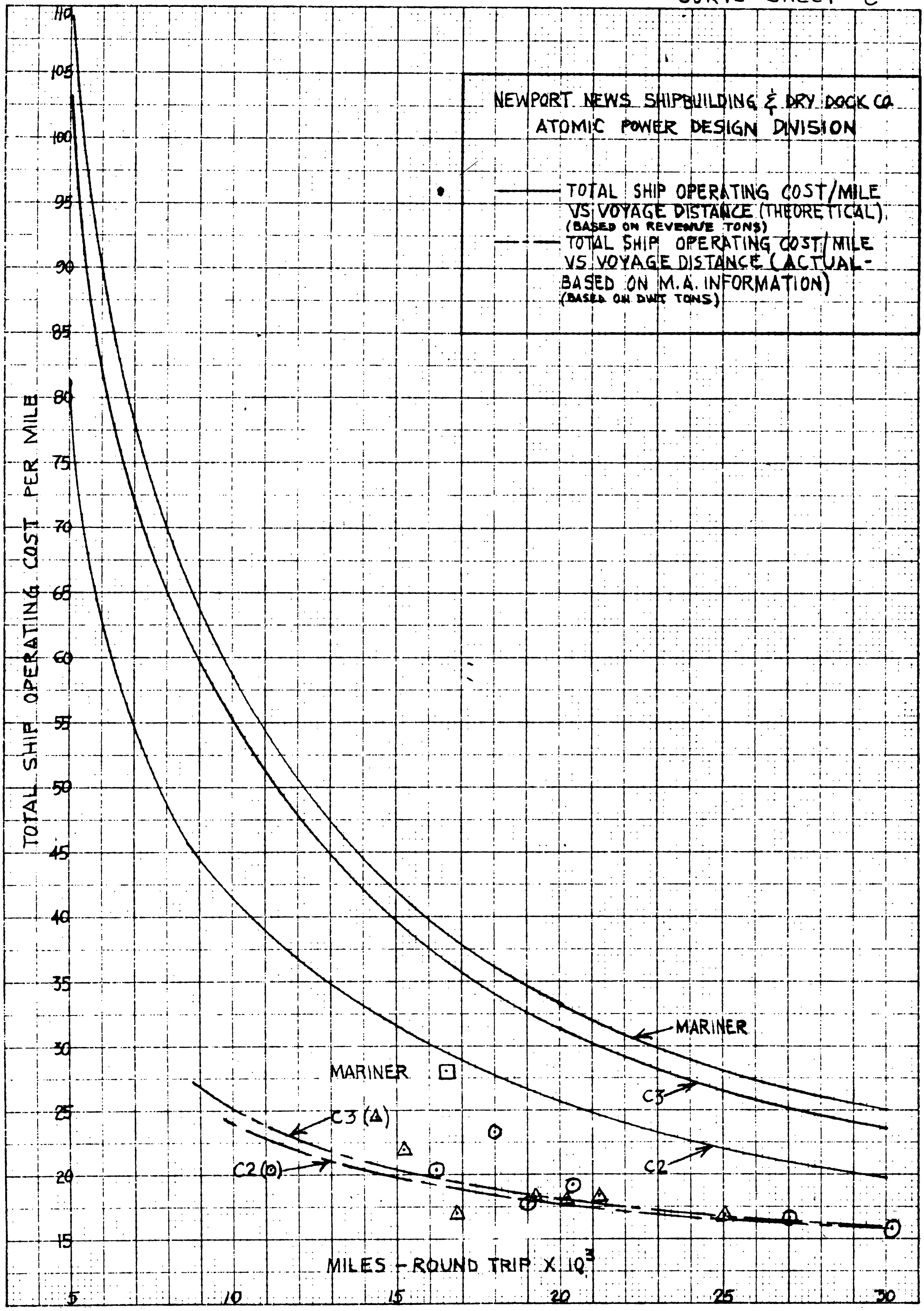

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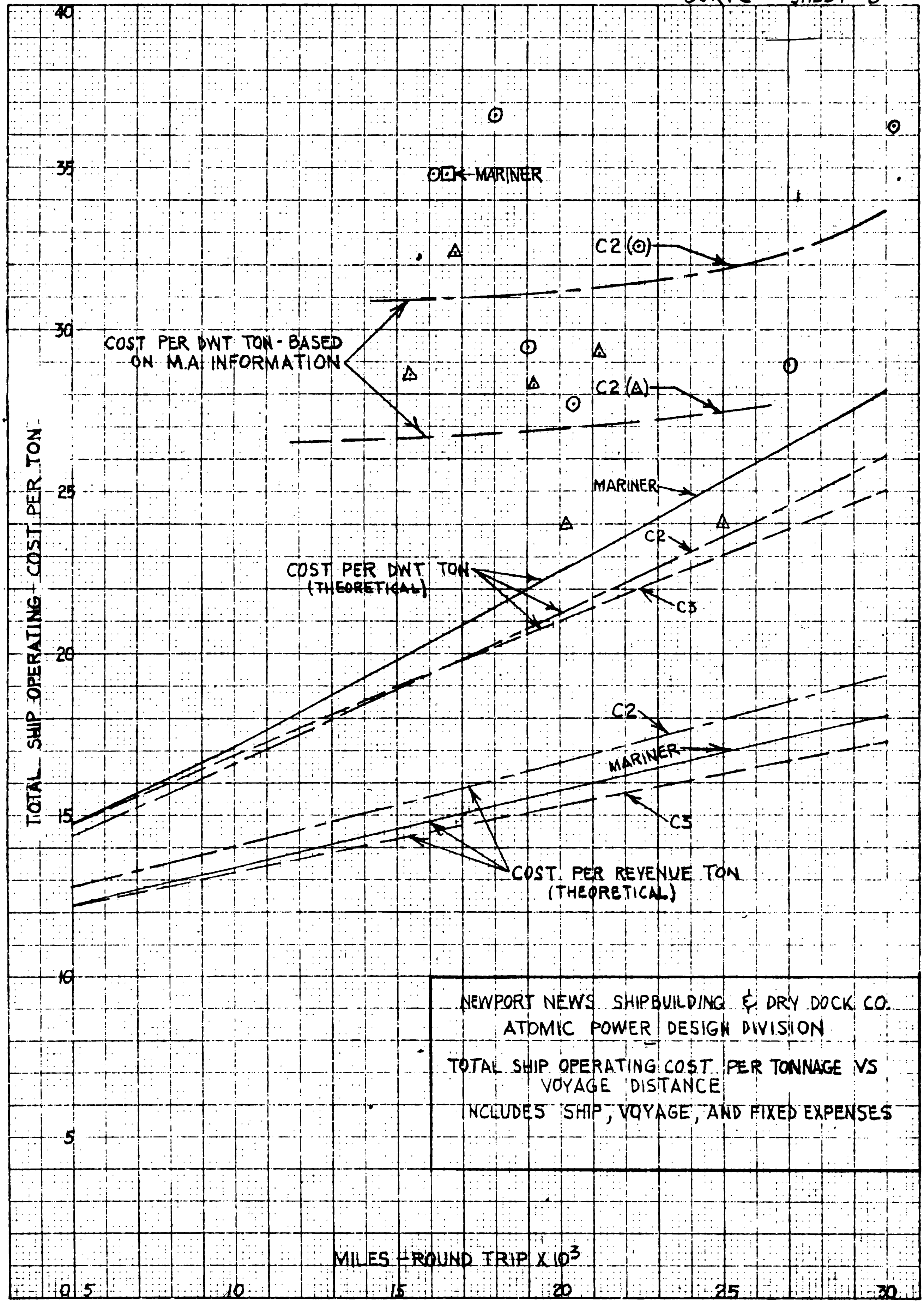

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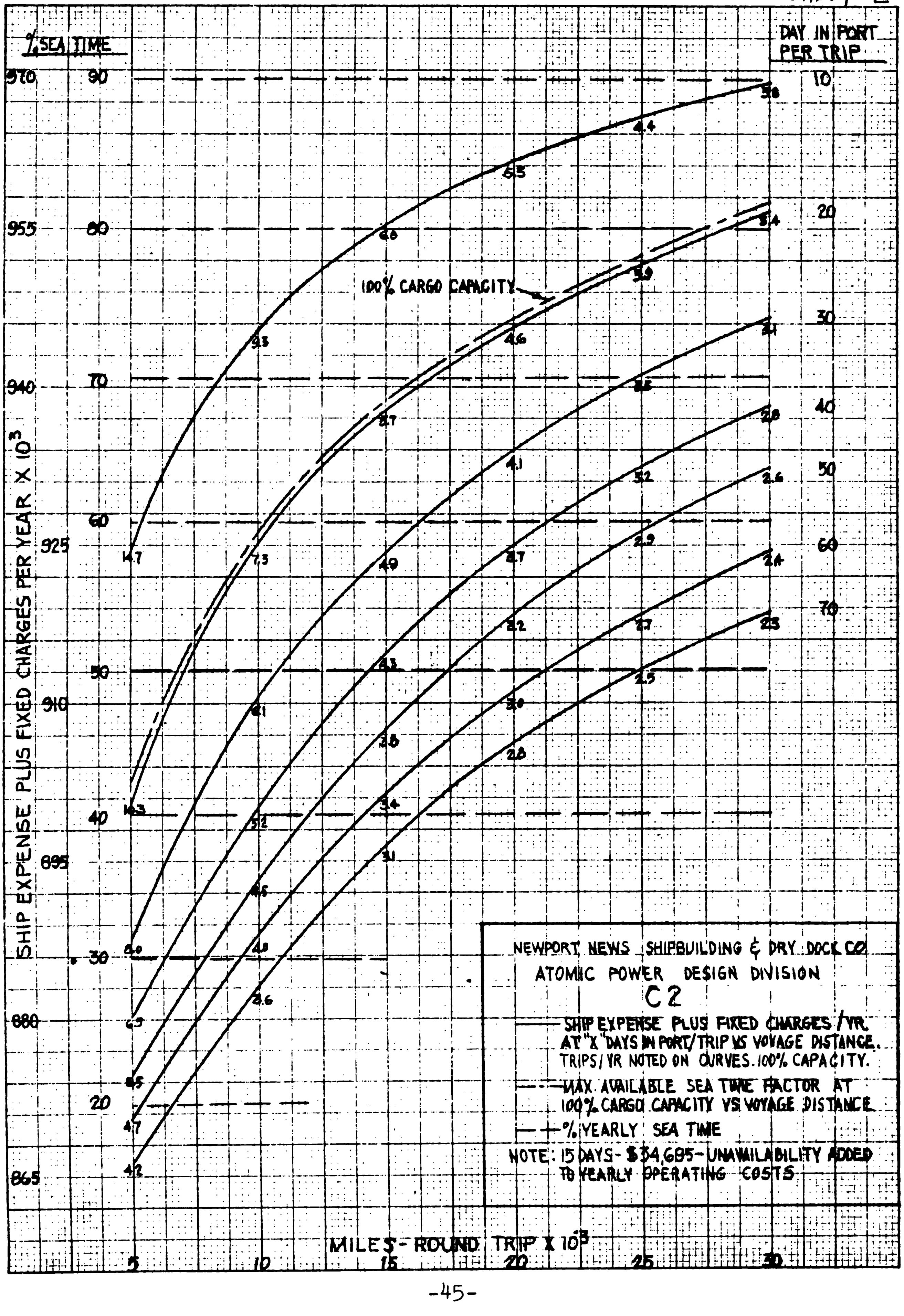

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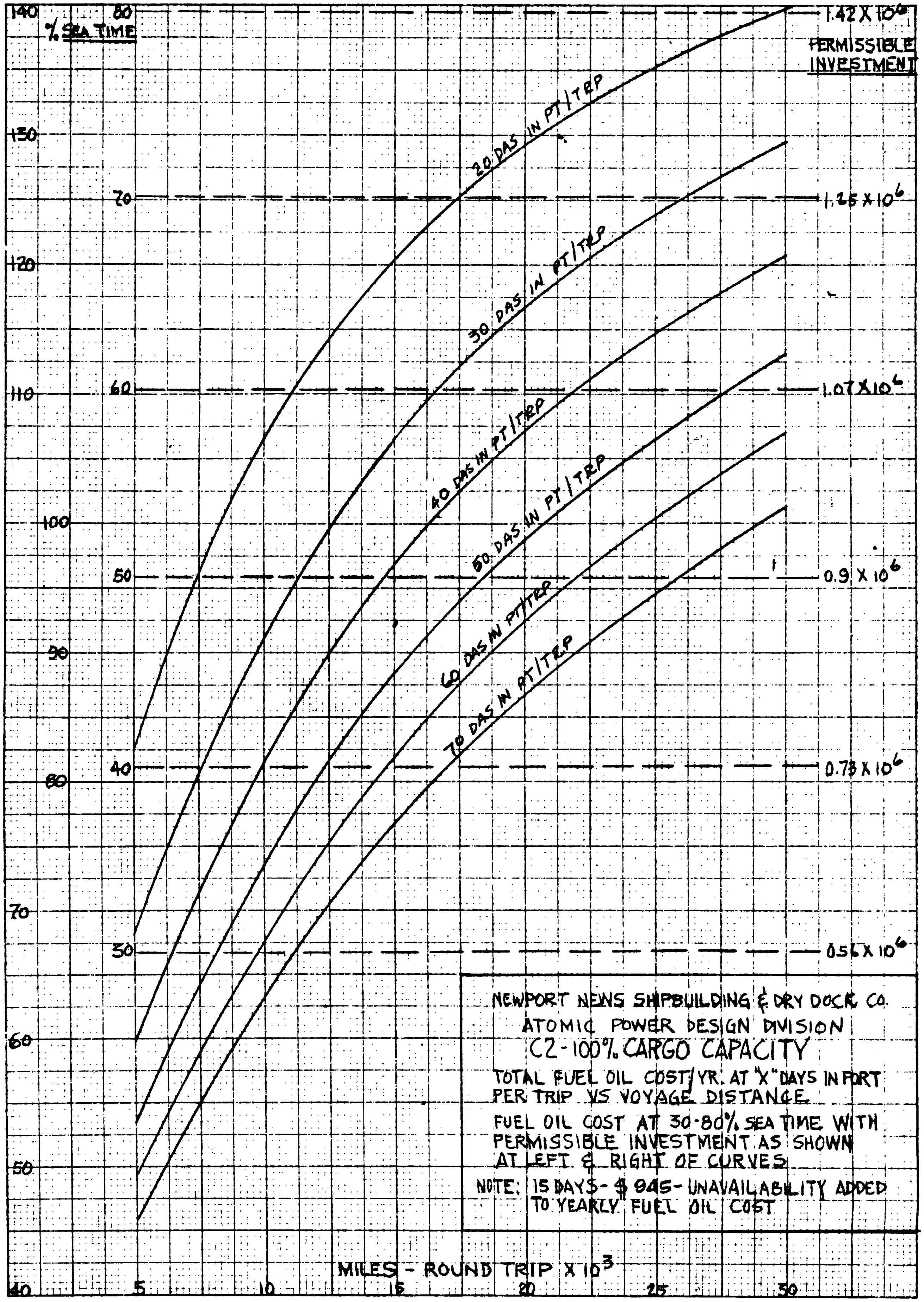


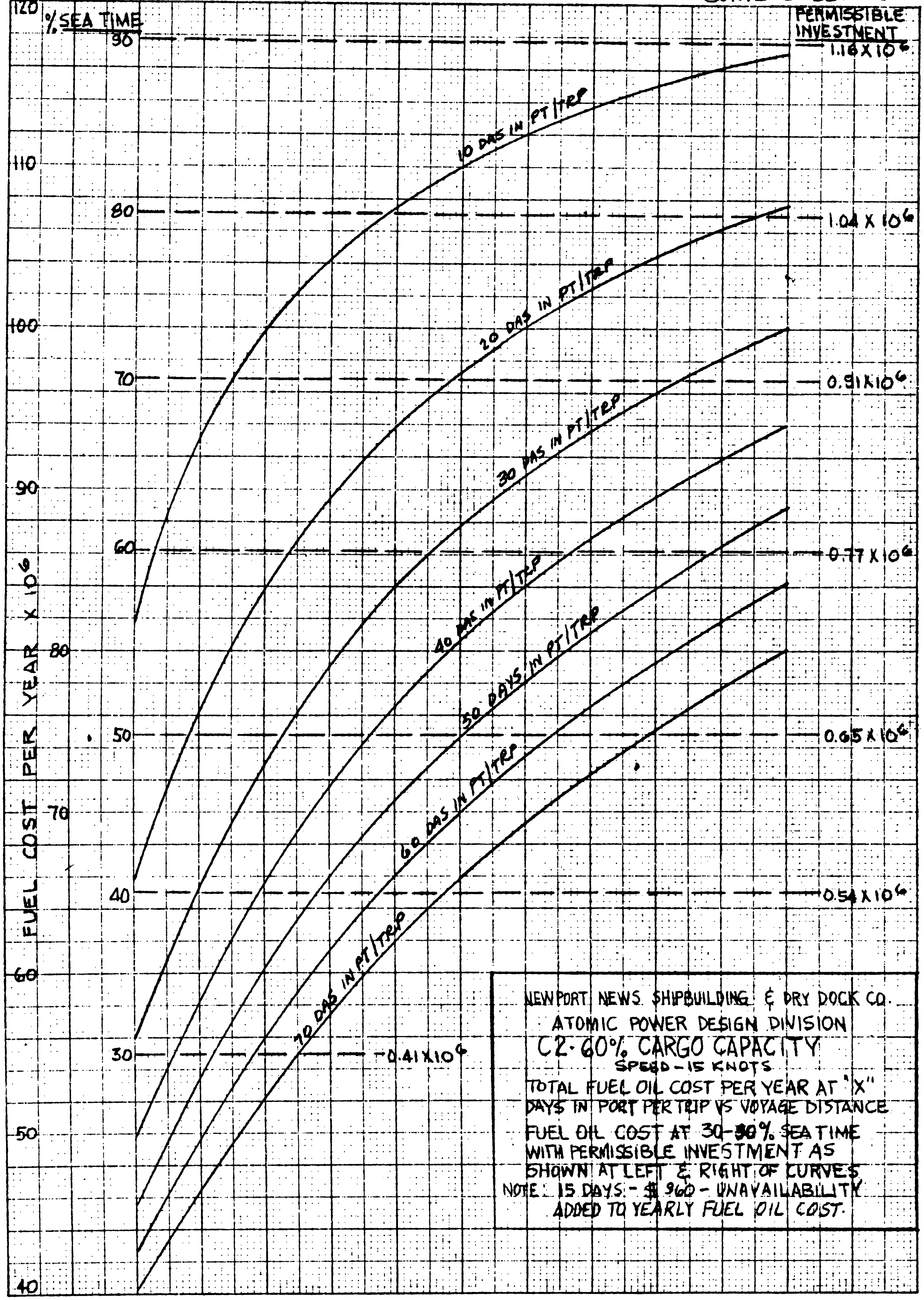
NEWPORT NEWS SHIPBUILDING & DRY DOCK CO.
ATOMIC POWER DESIGN DIVISION
C2-100% CARGO CAPACITY

TOTAL FUEL OIL COST/YR. AT "X" DAYS IN PORT PER TRIP VS VOYAGE DISTANCE

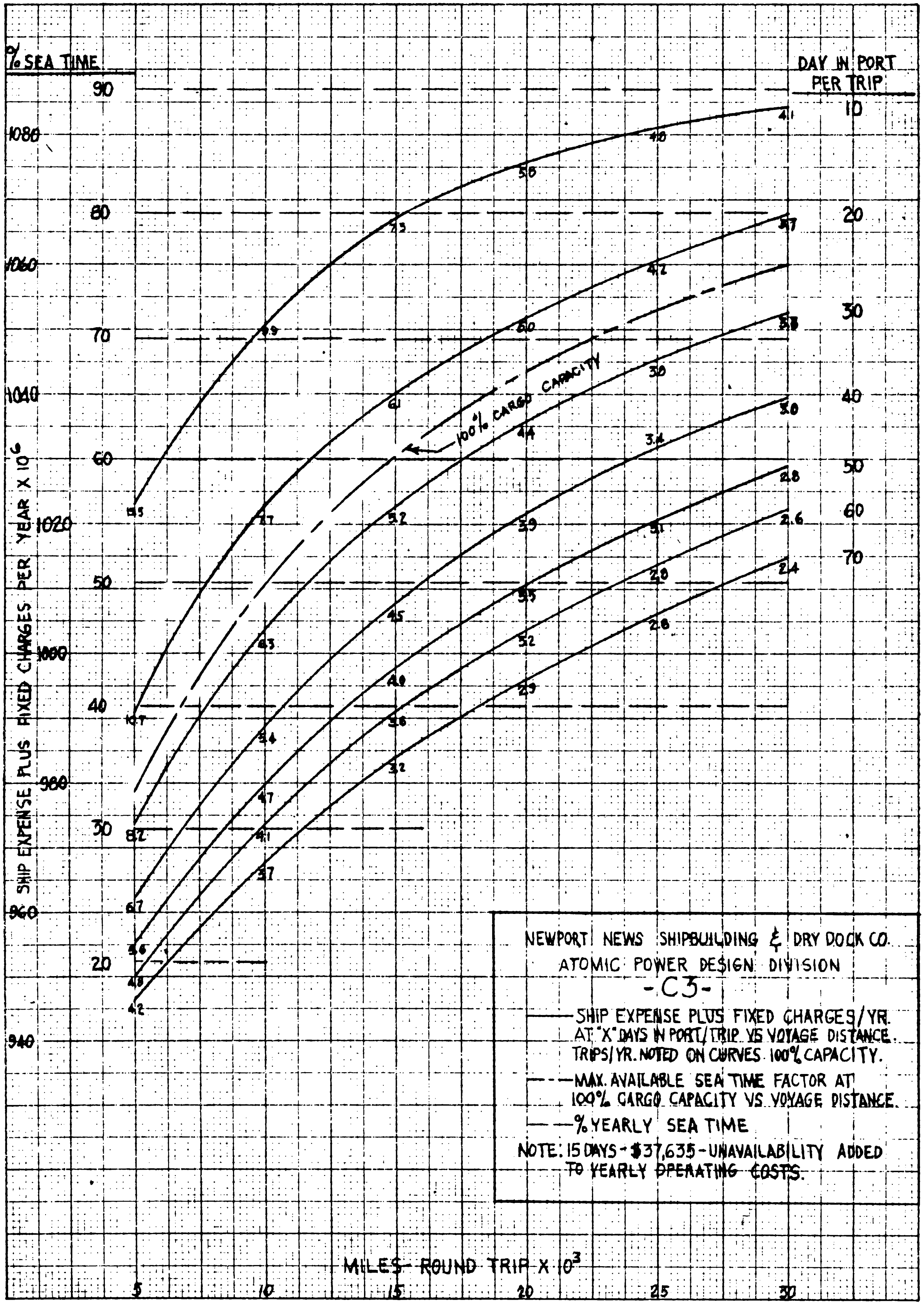
FUEL OIL COST AT 30-80% SEA TIME WITH PERMISSIBLE INVESTMENT AS SHOWN AT LEFT & RIGHT OF CURVES

NOTE: 15 DAYS - \$ 945 - UNAVAILABILITY ADDED TO YEARLY FUEL OIL COST

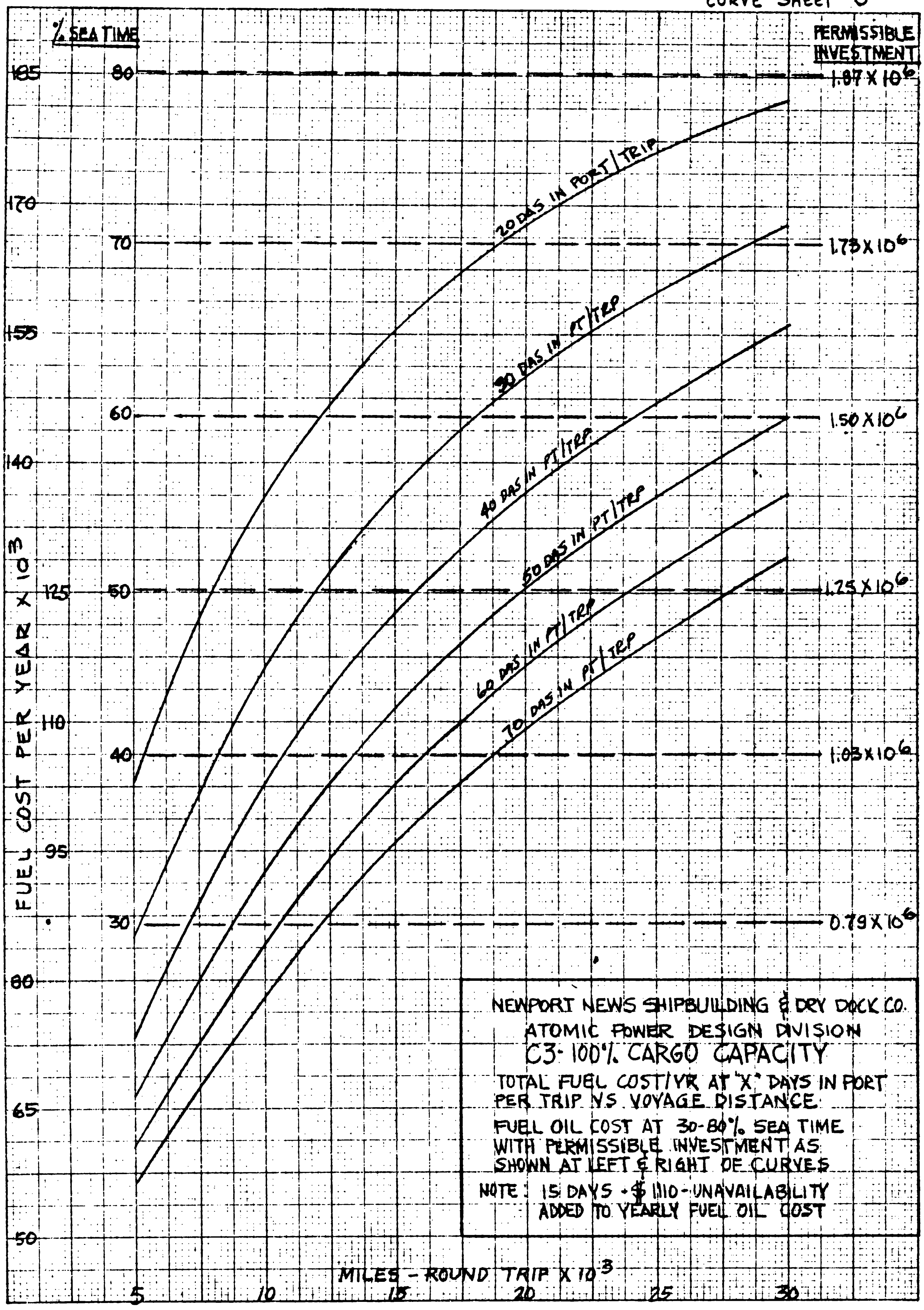
CURVE SHEET "G"



NEWPORT NEWS SHIPBUILDING & DRY DOCK CO.
ATOMIC POWER DESIGN DIVISION
C2-60% CARGO CAPACITY
SPEED - 15 KNOTS
TOTAL FUEL OIL COST PER YEAR AT "X"
DAYS IN PORT PER TRIP VS VOYAGE DISTANCE
FUEL OIL COST AT 30-90% SEA TIME
WITH PERMISSIBLE INVESTMENT AS
SHOWN AT LEFT & RIGHT OF CURVES
NOTE: 15 DAYS - $960 - UNAVAILABILITY
ADDED TO YEARLY FUEL OIL COST.

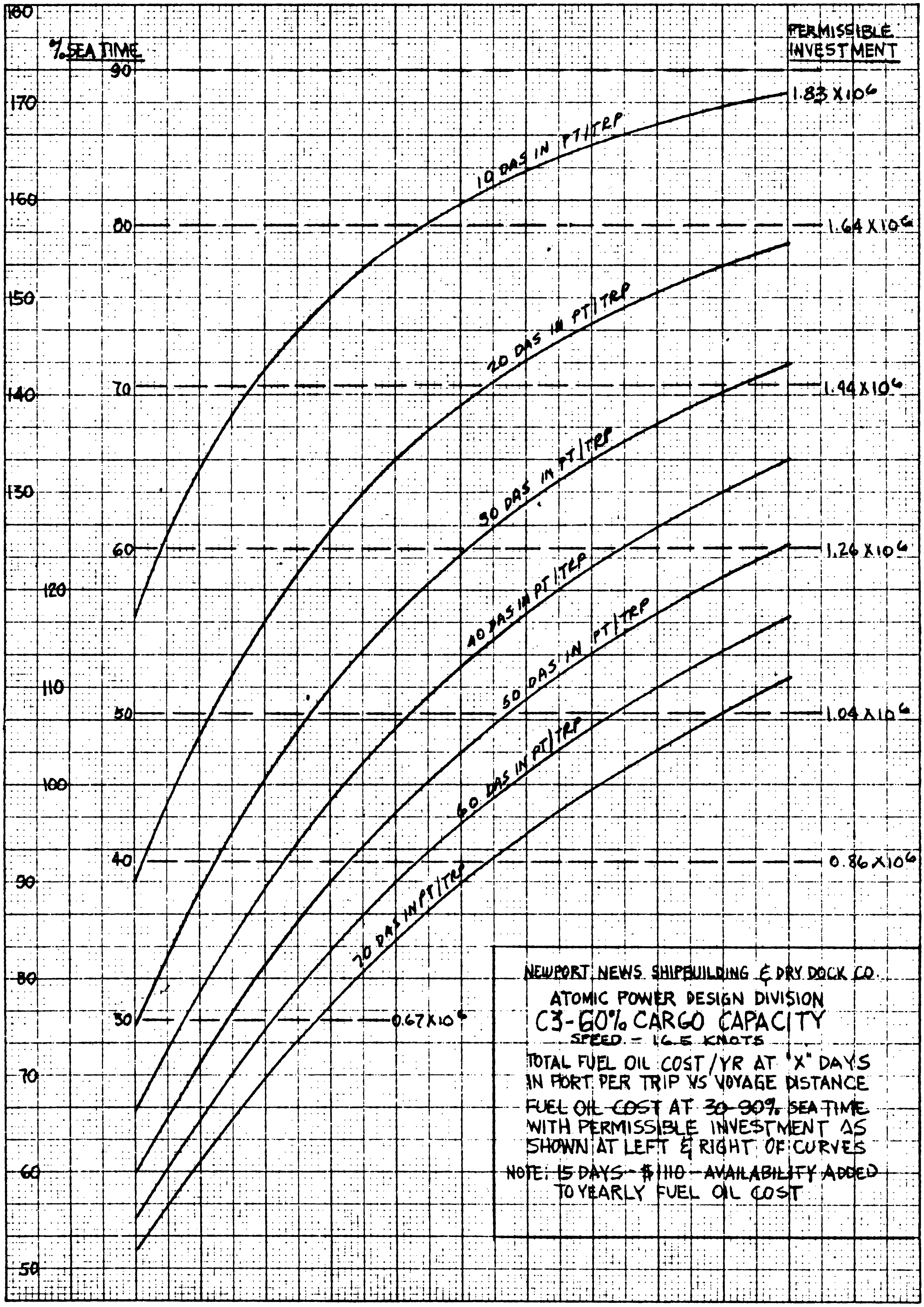

% SEA TIME
90
80
70
60
50
40
30
20
1080
1060
1040
1020
1000
980
960
940
SHIP EXPENSE PLUS FIXED CHARGES PER YEAR X 10^6
DAY IN PORT PER TRIP
10
20
30
40
50
60
70
15.5
9.9
7.3
5.8
4.8
4.1
10.7
7.7
6.1
5.0
4.2
3.7
8.7
6.3
5.2
4.4
3.8
3.3
6.7
5.4
4.5
3.9
3.4
3.0
5.6
4.7
4.0
3.5
3.1
2.8
4.8
4.1
3.6
3.2
2.8
2.6
4.2
3.7
3.2
2.9
2.6
2.4
100% CARGO CAPACITY
MILES ROUND TRIP X 10^3
5
10
15
20
25
30
NEWPORT NEWS SHIPBUILDING & DRY DOCK CO.
ATOMIC POWER DESIGN DIVISION
-C3-
——SHIP EXPENSE PLUS FIXED CHARGES/YR. AT "X" DAYS IN PORT/TRIP VS VOYAGE DISTANCE. TRIPS/YR. NOTED ON CURVES 100% CAPACITY.
- - - MAX. AVAILABLE SEA TIME FACTOR AT 100% CARGO CAPACITY VS VOYAGE DISTANCE.
— — — % YEARLY SEA TIME
NOTE: 15 DAYS - $37,635 - UNAVAILABILITY ADDED TO YEARLY OPERATING COSTS.

CURVE SHEET "J"



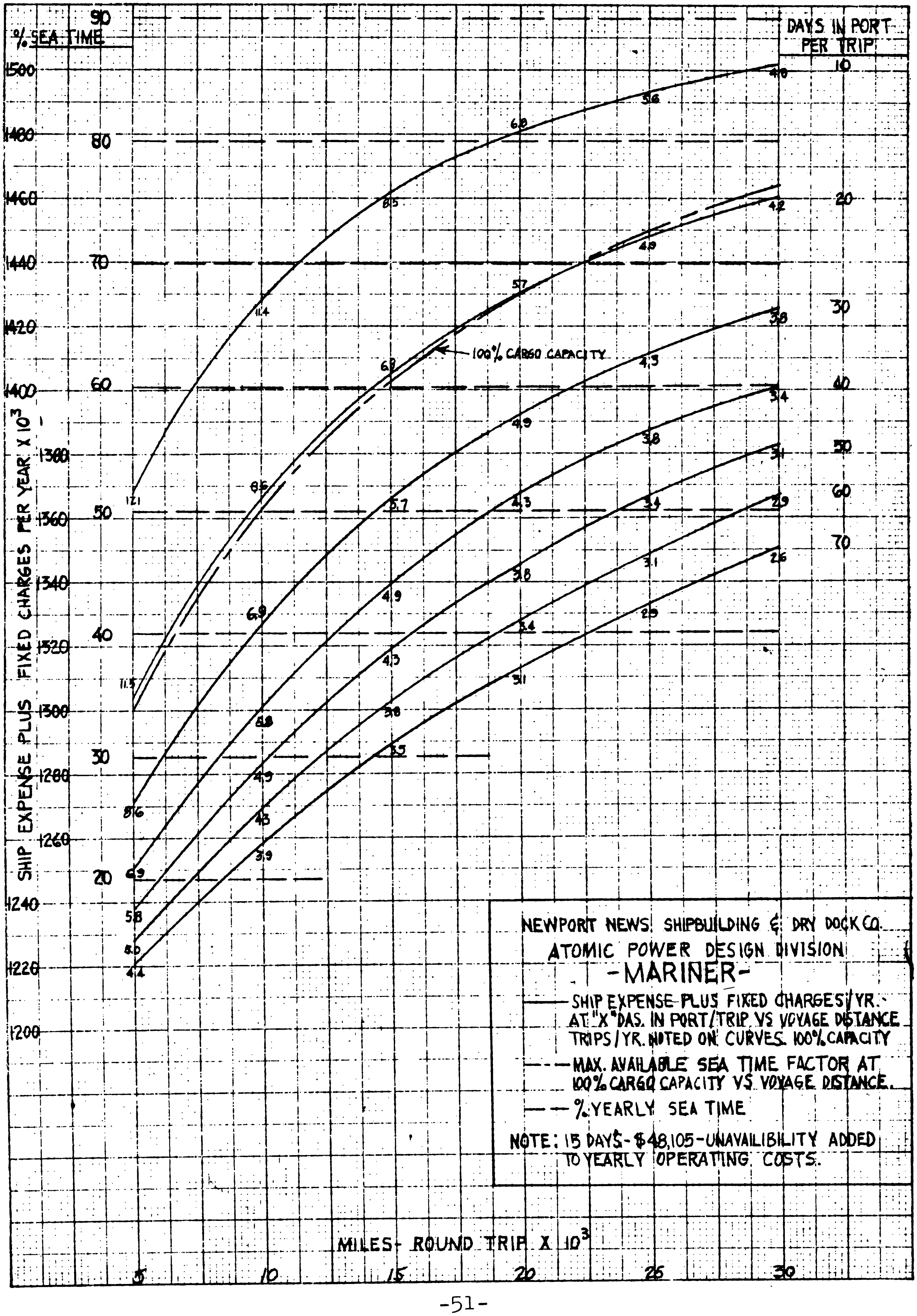
NEWPORT NEWS SHIPBUILDING & DRY DOCK CO.
ATOMIC POWER DESIGN DIVISION
C3- 100% CARGO CAPACITY
TOTAL FUEL COST/YR AT "X" DAYS IN PORT PER TRIP VS VOYAGE DISTANCE
FUEL OIL COST AT 30-80% SEA TIME WITH PERMISSIBLE INVESTMENT AS SHOWN AT LEFT & RIGHT OF CURVES
NOTE: 15 DAYS - $1110 - UNAVAILABILITY ADDED TO YEARLY FUEL OIL COST

CURVE SHEET "K"

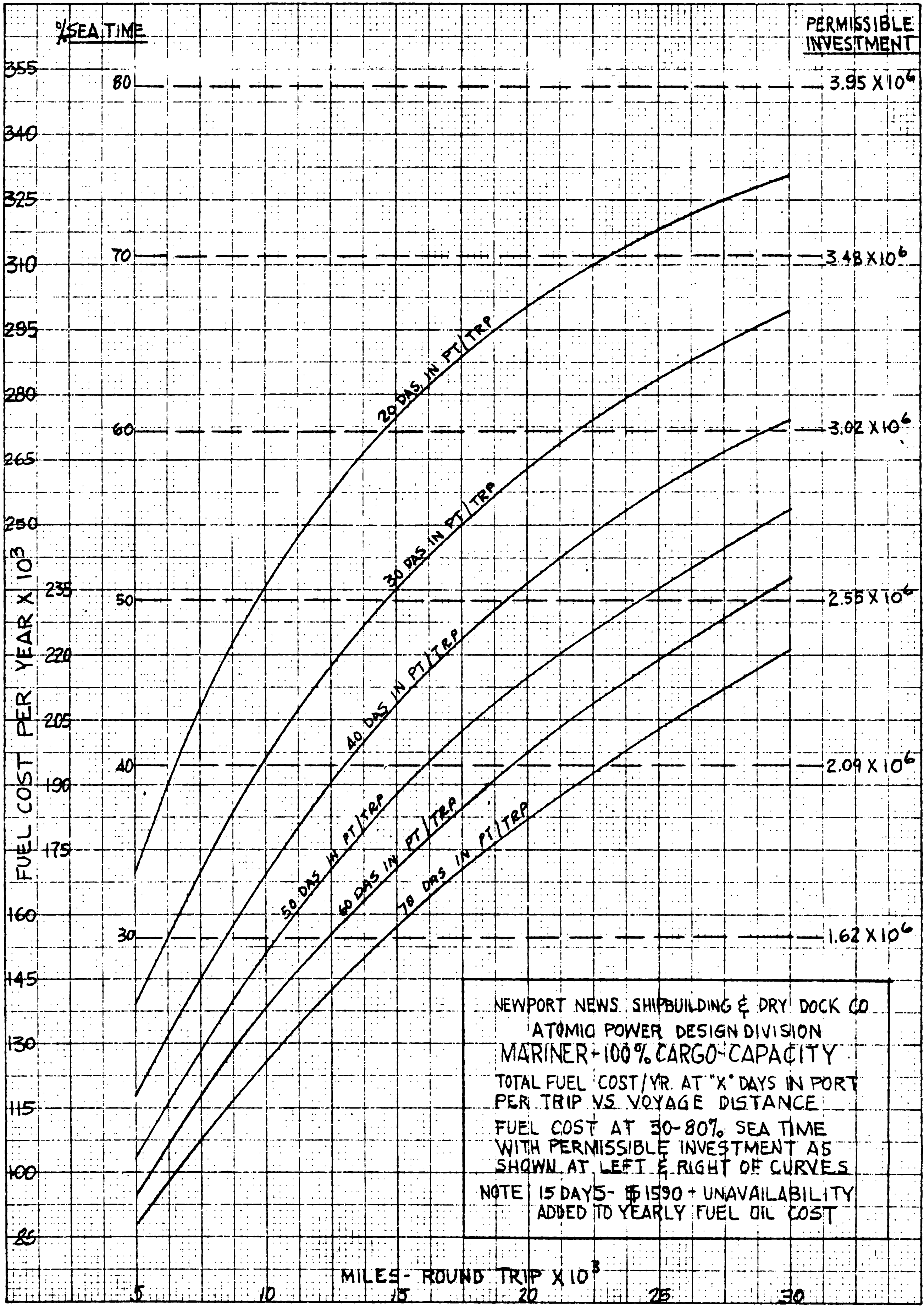


NEWPORT NEWS SHIPBUILDING & DRY DOCK CO.
ATOMIC POWER DESIGN DIVISION
C3-60% CARGO CAPACITY
SPEED - 16.5 KNOTS
TOTAL FUEL OIL COST/YR AT "X" DAYS IN PORT PER TRIP VS VOYAGE DISTANCE
FUEL OIL COST AT 30-90% SEA TIME WITH PERMISSIBLE INVESTMENT AS SHOWN AT LEFT & RIGHT OF CURVES
NOTE: 15 DAYS - $110 - AVAILABILITY ADDED TO YEARLY FUEL OIL COST

CURVE SHEET "L"



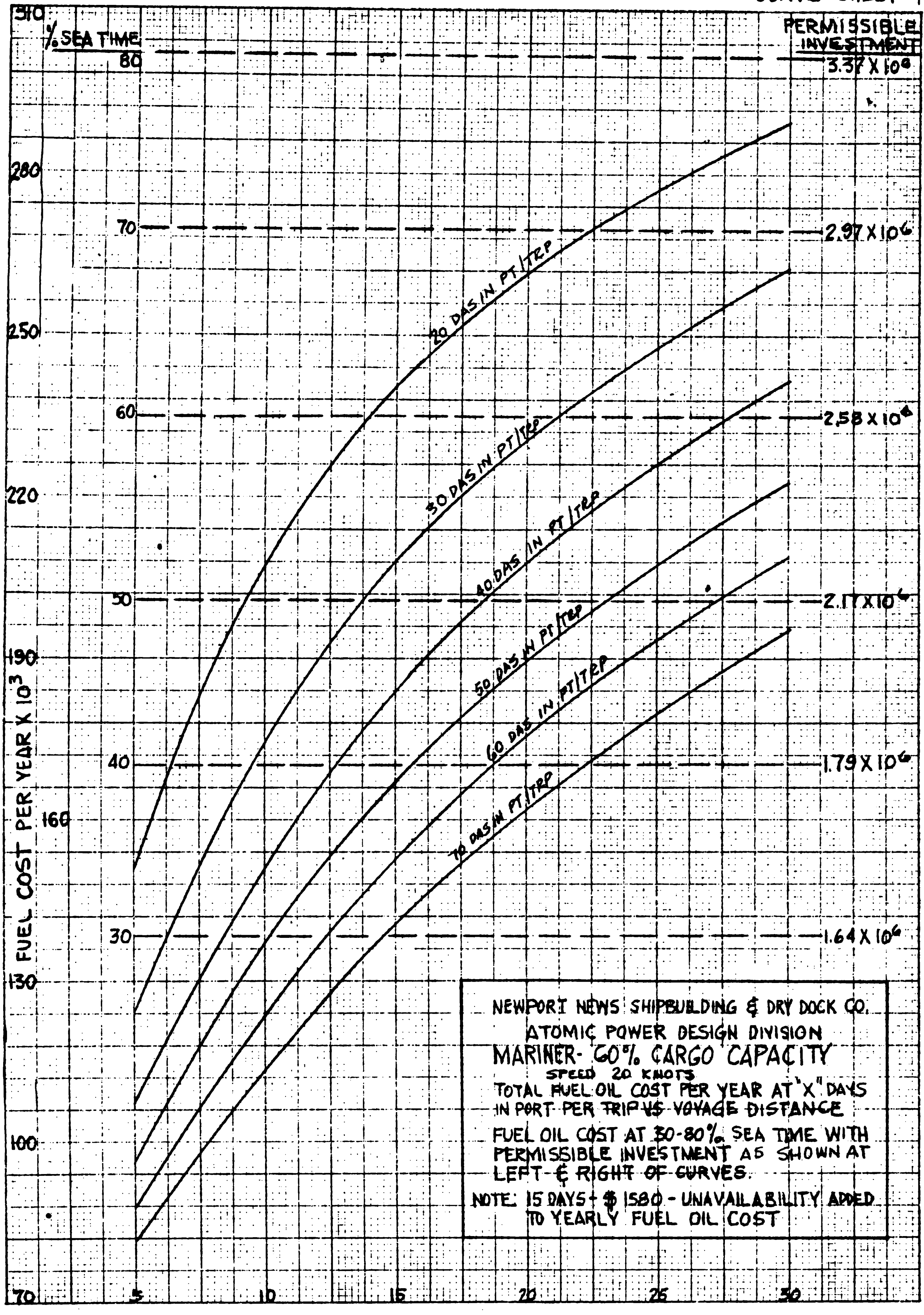
CURVE SHEET "M"



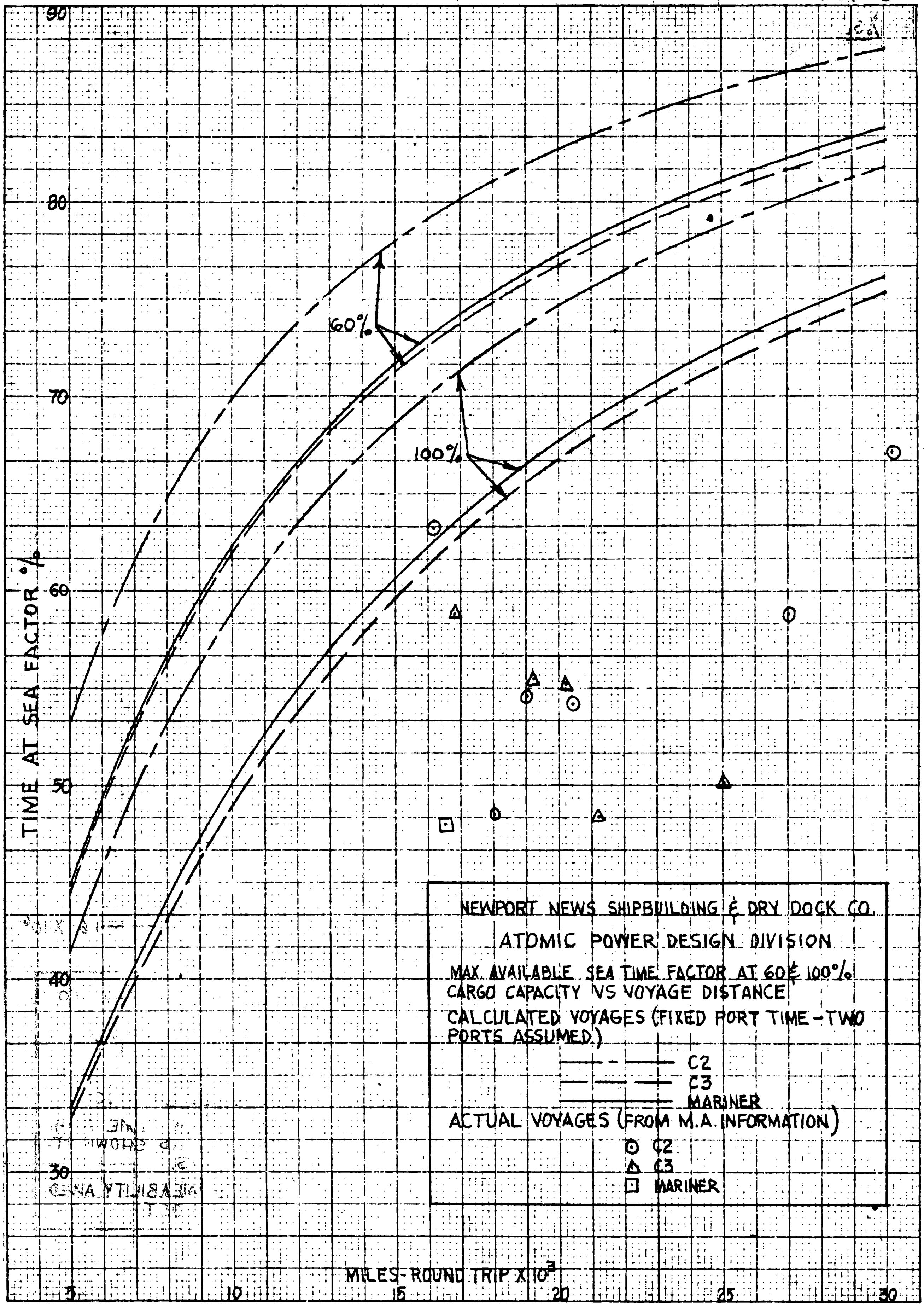
NEWPORT NEWS SHIPBUILDING & DRY DOCK CO
ATOMIC POWER DESIGN DIVISION
MARINER-100% CARGO-CAPACITY
TOTAL FUEL COST/YR. AT "X" DAYS IN PORT PER TRIP VS. VOYAGE DISTANCE
FUEL COST AT 30-80% SEA TIME WITH PERMISSIBLE INVESTMENT AS SHOWN AT LEFT & RIGHT OF CURVES

NOTE 15 DAYS - $61590 + UNAVAILABILITY ADDED TO YEARLY FUEL OIL COST

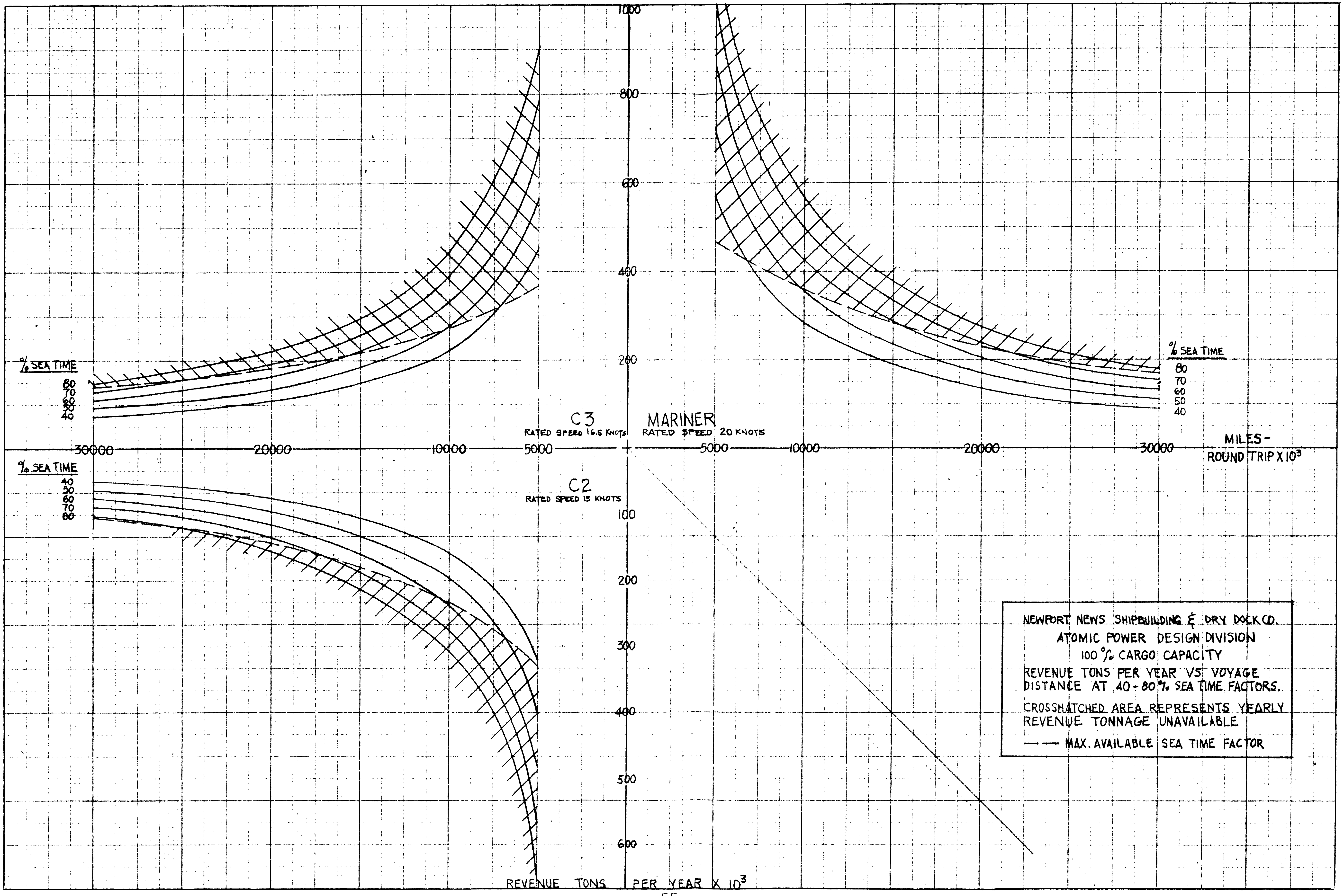
CURVE SHEET "N"



NEWPORT NEWS SHIPBUILDING & DRY DOCK CO.
ATOMIC POWER DESIGN DIVISION
MARINER- 60% CARGO CAPACITY
SPEED 20 KNOTS
TOTAL FUEL OIL COST PER YEAR AT "X" DAYS IN PORT PER TRIP VS VOYAGE DISTANCE
FUEL OIL COST AT 30-80% SEA TIME WITH PERMISSIBLE INVESTMENT AS SHOWN AT LEFT & RIGHT OF CURVES.
NOTE: 15 DAYS + $ 1580 - UNAVAILABILITY ADDED TO YEARLY FUEL OIL COST

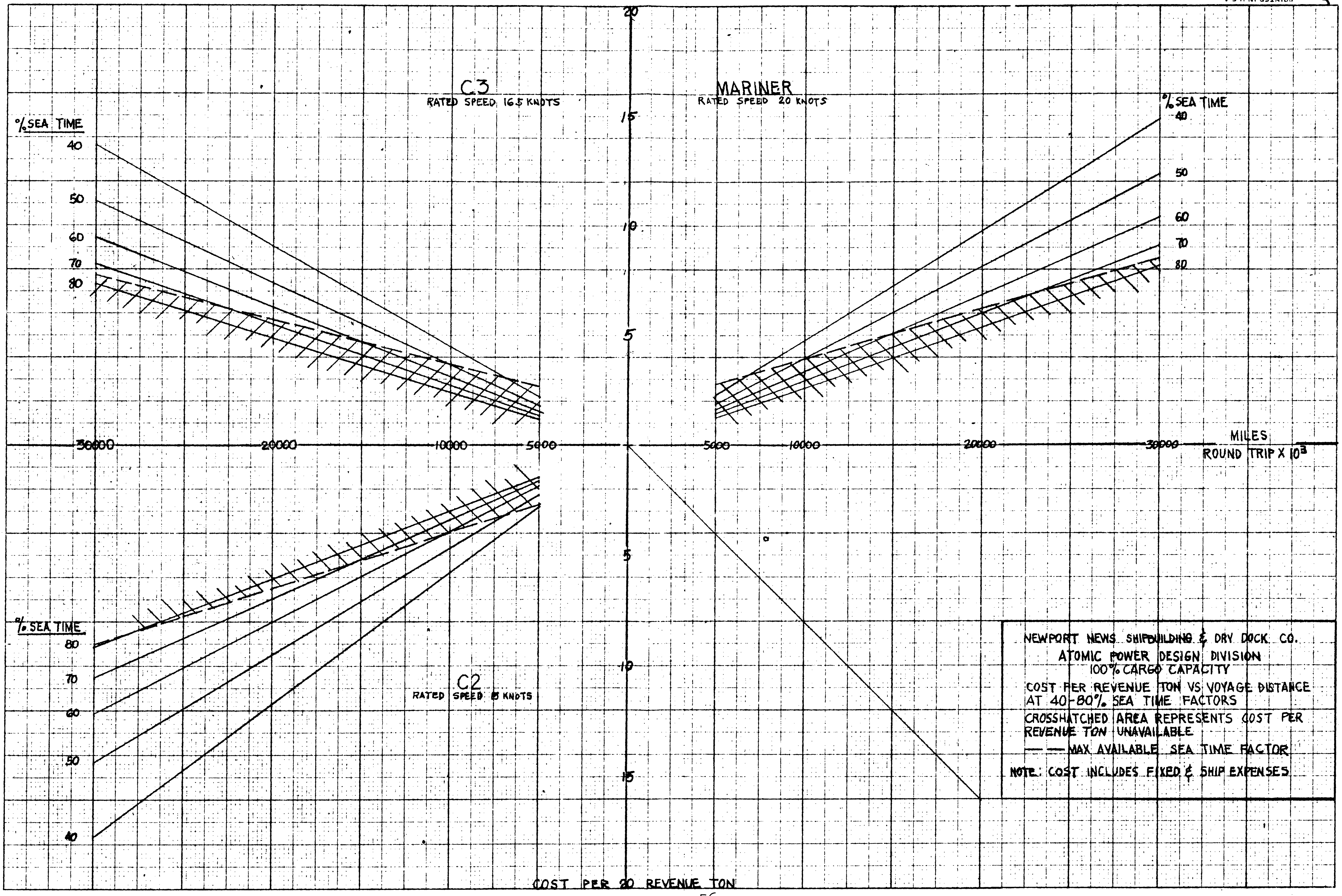

TIME AT SEA FACTOR %
MILES-ROUND TRIP X 10³
90
80
70
60
50
40
30
5
10
15
20
25
30
60%
100%
NEWPORT NEWS SHIPBUILDING & DRY DOCK CO.
ATOMIC POWER DESIGN DIVISION
MAX. AVAILABLE SEA TIME FACTOR AT 60 & 100%
CARGO CAPACITY VS VOYAGE DISTANCE
CALCULATED VOYAGES (FIXED PORT TIME - TWO PORTS ASSUMED)
C2
C3
MARINER
ACTUAL VOYAGES (FROM M.A. INFORMATION)
⊙ C2
△ C3
⊡ MARINER

CURVE SHEET "P"



NEWPORT NEWS SHIPBUILDING & DRY DOCK CO.
ATOMIC POWER DESIGN DIVISION
100 % CARGO CAPACITY
REVENUE TONS PER YEAR VS VOYAGE DISTANCE AT 40-80% SEA TIME FACTORS.
CROSSHATCHED AREA REPRESENTS YEARLY REVENUE TONNAGE UNAVAILABLE
— — MAX. AVAILABLE SEA TIME FACTOR

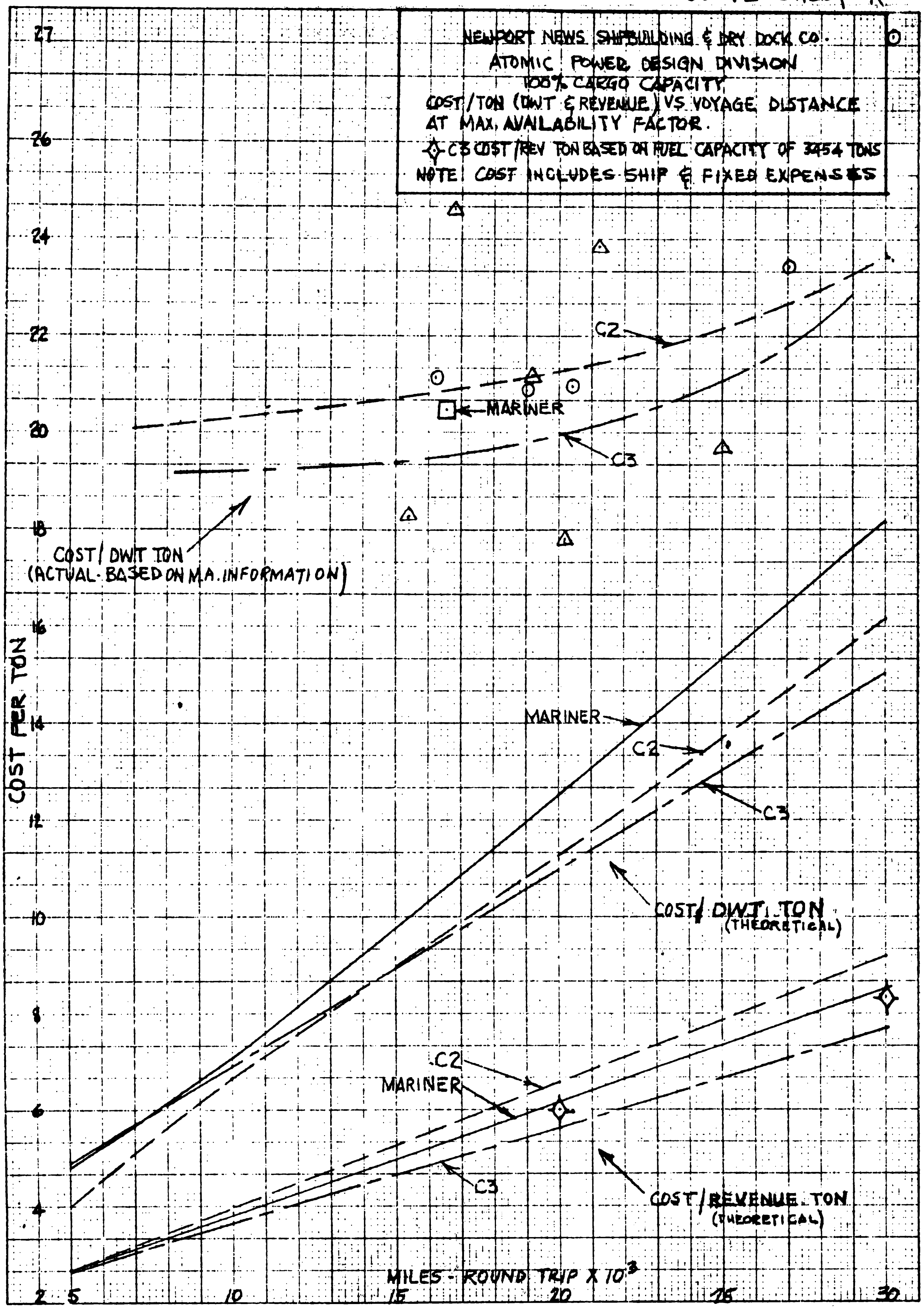
CURVE SHEET "Q"



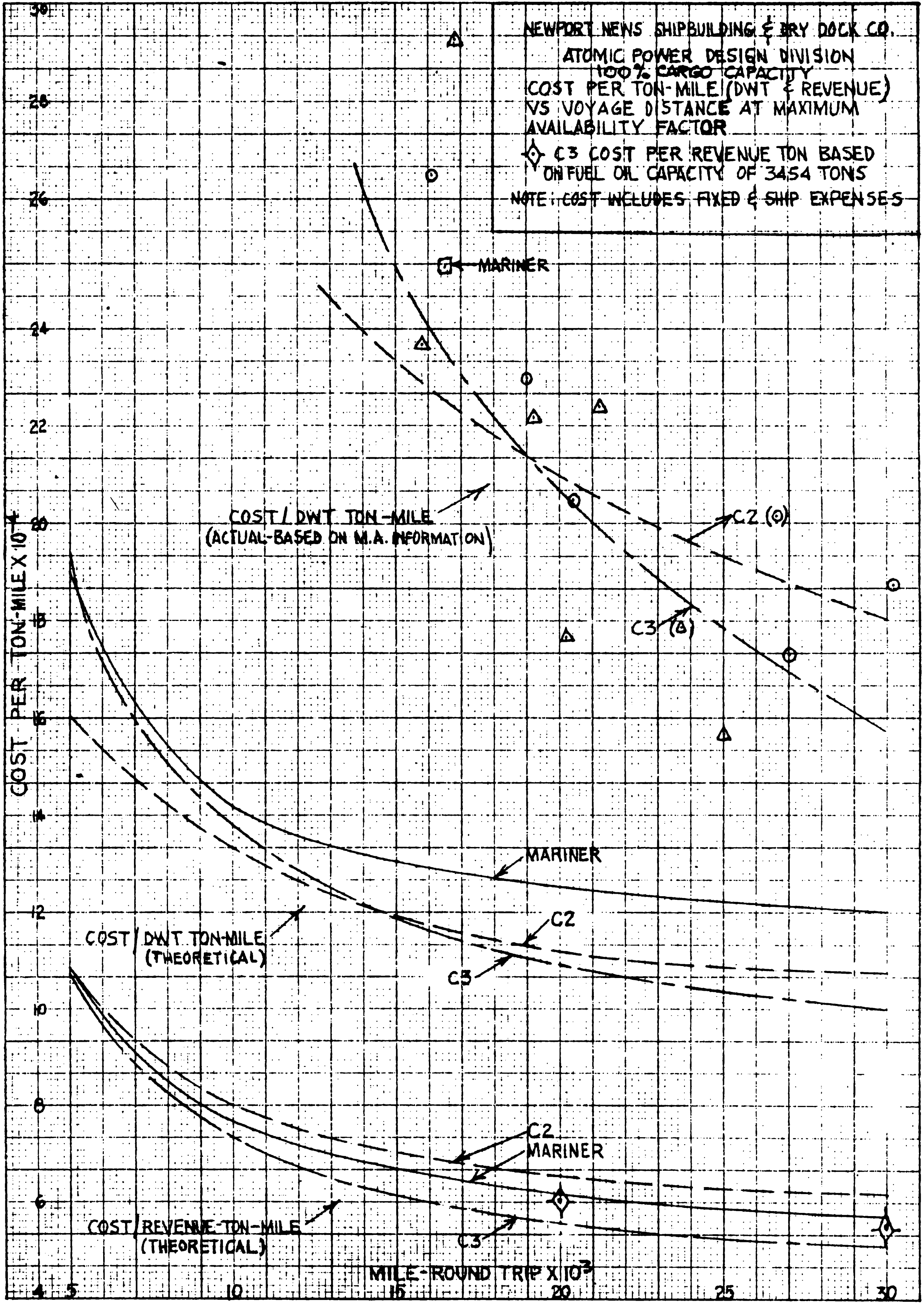
NEWPORT NEWS SHIPBUILDING & DRY DOCK CO.
ATOMIC POWER DESIGN DIVISION
100% CARGO CAPACITY
COST PER REVENUE TON VS VOYAGE DISTANCE AT 40-80% SEA TIME FACTORS
CROSSHATCHED AREA REPRESENTS COST PER REVENUE TON UNAVAILABLE
— — MAX AVAILABLE SEA TIME FACTOR

NOTE: COST INCLUDES FIXED & SHIP EXPENSES

CURVE SHEET "R"



CURVE SHEET "S"



NEWPORT NEWS SHIPBUILDING & DRY DOCK CO.
ATOMIC POWER DESIGN DIVISION
100% CARGO CAPACITY
COST PER TON-MILE (DWT & REVENUE)
VS VOYAGE DISTANCE AT MAXIMUM
AVAILABILITY FACTOR

◇ C3 COST PER REVENUE TON BASED ON FUEL OIL CAPACITY OF 3454 TONS

NOTE: COST INCLUDES FIXED & SHIP EXPENSES