NUCLEAR MERCHANT SHIPS: AN ECONOMIC EVALUATION
- HARRY BENFORD

NUCLEAR MERCHANT SHIPS:
AN ECONOMIC EVALUATION

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ABSTRACT

Recent manifold increases in the price of fuel oil have aroused renewed interest in nuclear power for merchant ships. This interest is underscored by the Western World's continuing vulnerability to politically-motivated oil embargoes.

Nuclear power plants are most competitive with oil-fired plants at extremely high horsepowers. We are therefore led to consider initial application in large ships that require great power: tankers, high speed containerships, and liquefied gas carriers. Even in these favorable sectors of the merchant marine the prospects of nuclear power in its present configurations are cloudy. Such direct monetary benefits as do exist may not overcome the barriers erected by powerful environmental-protection groups.

Eventually, as oil becomes ever-scarcer and as experience demonstrates their safety and reliability, nuclear ships should become politically feasible. But they may not have the field to themselves as the successor to oil-fired plants. The practical exhaustion of petroleum from wells will probably not occur before the end of the century. Meanwhile, other energy sources will surely be developed. Shale oil and coal-derived liquid fuels are reasonable examples. At the same time, there are reasons to be concerned about the worldwide availability of the uranium ores from which fissile fuels are derived. Although breeder reactors may be able to provide nuclear fuel, their inherent risks may make them politically unacceptable.

By A.D. 2000 we have reason to suspect that fission nuclear power, as we know it today, may be phasing out in favor of fusion power. Nuclear power in that form will have an unlimited source of raw material and will more readily satisfy the environmentalists. Although it may never be practical for shipboard propulsion, shore-based fusion plants may be able to produce synthetic fuels suitable for shipboard use. Fusion power must therefore be looked upon as one solution to our long-term energy requirements for merchant ships.

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Some of the kindly gentlemen named above are, I fear, going to be disappointed with my conclusions. Even those who aren't are likely to disagree with some of my controversial estimates, such divergence being a pleasantly stimulating characteristic of the subject. To all of these contributors I tender my sincere thanks and, where appropriate, my equally sincere apologies.

CONTENTS

INTRODUCTION

In the past decade or two, several careful studies have been published dealing with the economic potential of nuclear merchant ships.(1,3,6,8,9,11,12,21,22) These have, on the whole, reached rather discouraging conclusions, particularly when political considerations are taken into account. The majority view may be summarized in J.P. Kruseman's words:(11)

> The writer...can...on the basis of today's technology... no longer believe that nuclear merchant ships have a future, barring prestige, political, or military arguments.

Despite the pessimism of those earlier studies, recent manifold increases in the price of marine bunker oils now make it worthwhile to raise the question once again. We must recognize, moreover, that within a matter of decades the competition may not be with ordinary petroleum fuels but with other alternative forms of energy. Competitive fuels may be entirely synthetic, or they may be derived from coal or from oil in shale, or oil in tar sands. (This last is already a reality.) We must not overlook a gamut of possibilities ranging from sail to fast breeder reactors to fusion-derived fuels. Not even wood can be laughed off as a possibility. Moreover, we can expect to find that the form of power best suited to harbor tugs will not be the same as that best suited to small coasters; and larger, faster ships will perhaps find the best solution in some third alternative. About the only thing we can feel sure about is that energy costs are likely to be considerably higher than they are today. As these costs continue to rise, more and more seemingly unlikely sources of energy will have to be taken seriously. The marine industry is going to have to keep an open mind and to encourage research and development in several alternative paths.

From a national security point of view, most of the nations of the Western World and Japan should encourage developments that will relieve their dependence on foreign sources of energy. But this is not a political treatise, so I shall not say more on that point.

Let us then return to the question of the prospects for nuclear powered merchant ships.

CHARACTERISTICS OF NUCLEAR POWER

The primary advantage of nuclear power is of course a saving in cost of fuel. A necessary prerequisite, however, is that the power output be great enough to offset the inherently higher fixed costs. The ideal maritime application, then, would be in some kind of ship in which size, speed, and high use factor combine to produce large annual fuel bills. Three commonly cited candidates are tankers, high speed containerships, and liquefied gas carriers. There are practical reasons to disparage each of these candidates.

Tankers are dangerous enough without adding the risk of nuclear disaster. Moreover, nuclear power may only come into its own when the world runs out of oil--so what would we carry in a nuclear-powered tanker? High speed containerships are an unwanted offspring of conference rate-setting practices that have inadvertently led to increasingly uneconomic speeds. As energy costs go even higher, we are going to have to learn to accept more reasonable speeds in merchant ships. Moreover, there seems little logic in trying to push ships even faster when the cargo spends most of its time gathering cobwebs on the dock, or at other resting places along the way. Liquefied gas carriers have extremely expensive hulls. Relatively high powers are therefore justified, since higher speed allows fewer hulls to produce the same annual transport capacity.(1) Policy makers in this country were interested in the possibility of nuclear powered LNG (liquefied natural gas) carriers until they realized what our Cassandras would say about combining the horrors of Hiroshima with those of the *Von Hindenburg*.

Before going into the economics of nuclear propulsion for any of the above, it would be appropriate to recognize several distinctly discouraging facets of nuclear power, as we know it today. Miller(15) discusses current problems that must be faced. Principal among these are the unresolved issues of waste disposal, development of economically viable fuel reprocessing facilities, and the impending exhaustion of proven uranium reserves. (Miller claims we are likely to run out of uranium as fast as we run out of petroleum.) To their list I would add the delays that one encounters in gaining government approval for the construction and operation of nuclear plants. A study completed by Newport News engineers in 1976 (17) allowed a generous four years to build a large conventional tanker, but estimated another two and a quarter years for a corresponding nuclear tanker. Any businessman can tell you that being forced to estimate market conditions four years in the future is bad enough, but looking ahead for more than six years is better described as guess work. Converting that sort of disadvantage into dollar figures is not easy, but we may hope that governmental constraints will become less onerous as further experience with nuclear ships leads to enhanced confidence and more reasonable administrative procedures.

Exacerbating all these problems, we have disparate political groups that are allied in powerful opposition to further nuclear development. Breeder reactors, which would solve the nuclear fuel supply problem, are particularly unacceptable to these groups. O'Sullivan(18) describes the current nuclear inspired turmoil in Western Europe, and I can assure my European readers that the political situation in the United States is equally discouraging. I cannot pretend to judge the wisdom of those who so vehemently oppose nuclear power, but I must register some unease over the ratio of emotion to logic in their arguments.

AN ECONOMIC COMPARISON

Let us assume that engineering solutions can be found to the technical problems still facing the nuclear power industry. Let us also assume that the more rational members of the opposition become persuaded that their fears are unfounded. Might we then find that higher oil prices have ushered in the day of nuclear power for merchant ships? To help answer that question let us examine one representative case. What I present here is by no means a definitive study. It looks at just one challenger (nuclear power) and one defender (conventional power) without attempting to optimize either. It contains--of necessity--a fair share of guesses. Nevertheless, I believe you will find the comparison informative.

My work is derived from an ambitious and admirable study carried out at the Newport News shipyard in 1975-76.(17) Those investigators assessed the economic feasibility of nuclear power by comparing transport costs in two large tankers--one nuclear powered, the other oil-fired. Both ships are assumed to be in the crude-oil trade and on a voyage of 12,200 nautical miles, one way.

The proposed nuclear ship is powered by a modern pressurized water reactor (a Babcock and Wilcox CNSG type) with twin-screw steam turbine sets, producing a total of 110,000 maximum continuous SHP (55,000 SHP, each). The projected deadweight is about 588,000 long tons. The conventional counterpart is designed to provide exactly the same deadweight, but with a single screw oil-fired steam turbine drive of 60,000 maximum continuous SHP. Although the two horsepowers are considerably different, we have reason to believe that each is close to the optimum for its own propulsion system. Table I compares technical data on the two designs; Table II summarizes the operating data. All figures in these and other tables are from the Newport News study(17) except as specifically noted in the appendix.

TABLE I

TECHNICAL DATA

	Nuclear	Conventional	Notes in Appendix
Total deadweight, long tons	587,653	587,653	1.
Cargo per trip, long tons	585,600	576,500	2.
SHP max. continuous	110,000	60,000	
SHP service (at 90% max.)	99,000	54,000	
Sea speed in ballast, knots	19.10	15,28	
Sea speed loaded	17.75	14.20	
Mean sea speed	18.43	14.74	
Fuel rate for conventional ship	-	0.42 $\frac{\text{lbs}}{\text{SHP-hr}}$	3.
Crew complement	39	34	4.

TABLE II

OPERATING DATA
(24,400 nautical mile round trip)

	Nuclear	Conventional	Notes in Appendix
Operating days per year	340	345	5.
Sea days per round trip	55.2	69.0	
Port days per round trip	3.0	3.0	
Total days per round trip	58.2	72.0	
Round trips per year	5.842	4.793	
Cargo per year, long tons	3,421,000	2,763,000	

TABLE III

CONSTRUCTION COSTS
(Millions of dollars)

	Nuclear	Conventional	Notes in Appendix
Construction cost, U.S.	$315.06	$226.91	6,7,8.
Construction cost, non-U.S.	204.79	147.49	9.
Nuclear licenses & fees	0.50	0	
Total non-U.S. cost incl. fees	205.29	147.49	
Future total cost, non-U.S.	184.76	147.49	10,11

TABLE IV

ECONOMIC EVALUATION
(Annual Costs in $1000)

	Nuclear	Conventional	Notes in Appendix
Crew wages	$1630	$1353	12.
Subsistence	107	94	13.
Maintenance & repair	3695	2950	14.
Hull & machinery insurance	2079	1659	15.
Protection & indemnity insurance	1470	735	16.
Stores & supplies	349	325	17.
Overhead & misc	726	660	18.
Port charges	1607	1054	19,20
Nuclear shore staff	94	0	21.
Nuclear inspection	65	0	-
Nuclear license	25	0	-
Nuclear refueling	2266	0	22
Nuclear fuel	8662	0	23
Oil fuel	0	8175	24,25
Annual operating costs	22775	17005	
Minimum CRF	0.1175	0.1175	26
Min. annual cost of capital recovery	21709	17330	27
Min. average annual cost	44484	34335	28
Normal CRF	0.1538	0.1538	29
Normal annual cost of capital recovery	28416	22684	27
Normal average annual cost	51191	39689	28
Tons of cargo per year (1000)	3421	2763	30
RFR with min. cost of capital	$13.00	$12.43	31
RFR with normal cost of capital	$14.96	$14.36	31

I have taken the privilege of second-guessing the authors of the Newport News study on several points. For example, they assume that the conventional tanker would take on bunkers for the round trip at the loading port. I believe many owners would prefer to take on round trip bunkers at the discharge port. In this case, by so doing, they would add nearly 12,000 tons of cargo capacity per trip.

A more significant departure is a basic change I have made in economic setting. The Newport News study aims at realism in the immediate future, looking at ships to be placed in contract in 1977 and delivered in 1983. I prefer to look a little farther ahead, however, and have given the nuclear ship the benefit of learning-curve savings, resulting in a ten percent reduction in first cost. I assume that in time regulatory procedures will be improved so that the construction time for a nuclear ship will be no longer than that for a conventional ship. I assume that fuel oil prices will increase by another 25 percent (to $15 per barrel) and that conventional steam plants will be designed for correspondingly higher efficiencies.

Many other changes in assumptions are explained in the appendix.

The Newport News study goes to extraordinary lengths to recognize inflation during the years of construction and operation. That procedure is usually of only marginal benefit,(2) so the Newport News engineers present a second approach in which they start with January 1, 1977 dollar values and allow them to inflate (generally at 8 percent per year) until delivery on April 1, 1983. Thereafter they assume that costs and incomes will rise together and can therefore be ignored. I derive my cost estimates from that second approach.

In keeping with international interest in this matter, I have modified the Newport News figures--where appropriate--to reflect worldwide costs.

Tables III and IV show comparative economic data for the nuclear and conventional ships, culminating in projected values for required freight rate as follows:

Nuclear ship	$14.96 per long ton
Conventional ship	$14.36 per long ton
Difference	$ 0.60 or 4 percent

The predicted difference is insignificant, given the roughness of many of the component figures. An owner would certainly be justified in selecting a nuclear ship for the given service if he felt the intangible factors favored such a decision. Unfortunately for nuclear power, most of the intangible factors (such as uncertainty about future regulations) seem to be working against it--at least in today's milieu. But who can tell what the picture may be in another ten, or even five, years? Some may argue that the world is running out of oil and so fuel oil prices are bound to go higher. Unfortunately, uranium resources also seem to be on their way to exhaustion. We can expect prices for the two kinds of fuels to rise more or less in parallel.

It may also turn out that as oil prices go up the oil-fired steam plant may be replaced by medium-speed geared diesels, even in the largest merchant ships. In short, the nuclear challenger may find itself up against a more formidable defender.

The appendix contains notes justifying many of the numbers presented in Tables I to IV. You are welcome to take exception to any of my assumptions accordingly. Everything is spread before you and changes are easily made. There is most assuredly room to haggle over every one of my numbers, and you may be able to convince yourself that the economics favor the nuclear alternative. But remember three discouraging facts. One is that we have examined here what must be considered a close-to-optimum application of marine nuclear power. Another is that most of the intangible factors and political forces are working against the nuclear alternative. The third is that fissile fuels face exhaustion along with oil. I think we must agree that nuclear power of contemporary design is unlikely to solve the long-term needs of merchant ship propulsion.

This is not to say that we should slam the door on nuclear energy. Early in the next century fusion power may become the leading contender to succeed petroleum as our major source of energy. Whether it will be suited to marine propulsion is another matter that we shall discuss in the next section.

FUSION POWER

Nuclear fusion differs from nuclear fission in that fusion involves a collision of two light atomic nuclei that combine to form a larger nucleus, and in so doing release energy. Although fusion power is not without its risks, they appear to be considerably less than those inherent in fission power. Of greater importance is the fact that the components of the fuel are to be found in virtually unlimited supply. The major component is deuterium, an isotope of hydrogen, which can be extracted from sea water. In theory, there is enough deuterium in one gallon of water to produce energy equivalent to that obtained by burning 300 gallons of gasoline. (After all these years of using water to put out fires, it seems ironic to realize that each dousing gallon had within it all that "flammability.") Moreover, extracting the deuterium from a gallon of water costs only a few cents.(7) A second component of fusion fuel is tritium, another isotope of hydrogen. Tritium can be bred in a fusion reactor from a third material, lithium, that also serves as the primary coolant as well as a shield against gamma rays and debris from the fuel pellets.(7,14,16) Lithium can be derived from sea-water but is more readily available from land sources.

At least some engineers involved in fusion development believe that we may see one or more experimental fusion plants in operation as early as the year 2000. If we are lucky, commercial application might follow in another decade. There are, however, many problems still unsolved, and there is much guess work involved in trying to predict the timing of their solutions.(10,13,19)

Calculations show that nuclear fusion with deuterium can be sustained only at temperatures of over 400 million degrees Kelvin.(14) This can be reduced to 45 million degrees K if tritium is combined with deuterium.(14) Producing and containing such temperatures is, of course, the fundamental problem that must be solved before nuclear fusion power becomes a reality. After all, some scientists believe that the sun's interior is only 15 million degrees K!

One approach to the confinement problem involves the use of high temperature, ionized gas (plasma) held in place by a surrounding magnetic field. (Confining the plasma in a chamber without benefit of magnetic field would either melt the chamber or cool the plasma, or both.) Conceptual designs of a magnetic field reactor propose a torus, or doughnut-like, configuration. Fig. 1 shows ~~of~~ such a torus. Fig. 2 and 3 give an impression of the proposed overall arrangement. The tiny silhouettes near the number 18 in Fig. 2 (lower right hand corner) are the operators; and their relative size gives some indication of the scale. I think we can conclude that the magnetic field system is less than promising for shipboard application.

An altogether different approach is embodied in what is called inertially confined fusion systems. Prominent among these is laser fusion, in which tiny pellets containing deuterium and tritium, are struck by laser beams, producing temperatures sufficient to induce fusion. Fig. 4 shows one proposed design for a reactor of this type.(14) This particular concept is not advocated for shipboard use, but we may conclude that a laser fusion power system might well fit into a ship of even modest size, although we must remember that the lasers themselves may occupy considerable space.

When we come to look into the details of laser fusion, we find many of the discouragements that dog the application of shipboard fission power. The same scaling problem exists. That is, modest powers--say, less than 20,000 SHP--seem quite impractical. Shielding requirements would be roughly comparable because of neutrons given off during operation. Repairs would still involve delays awaiting radioactive decay.

But we must not overlook the advantages <u>vis-a-vis</u> fission power. Confinement requirements would be less stringent; the spent-fuel disposal problem would be more readily solved, and the dangers of radioactive contamination following collision or grounding would be appreciably lessened.

All in all, we should keep our eye on laser fusion power as an eventual successor to fossil fuels for merchant ships. Perhaps,

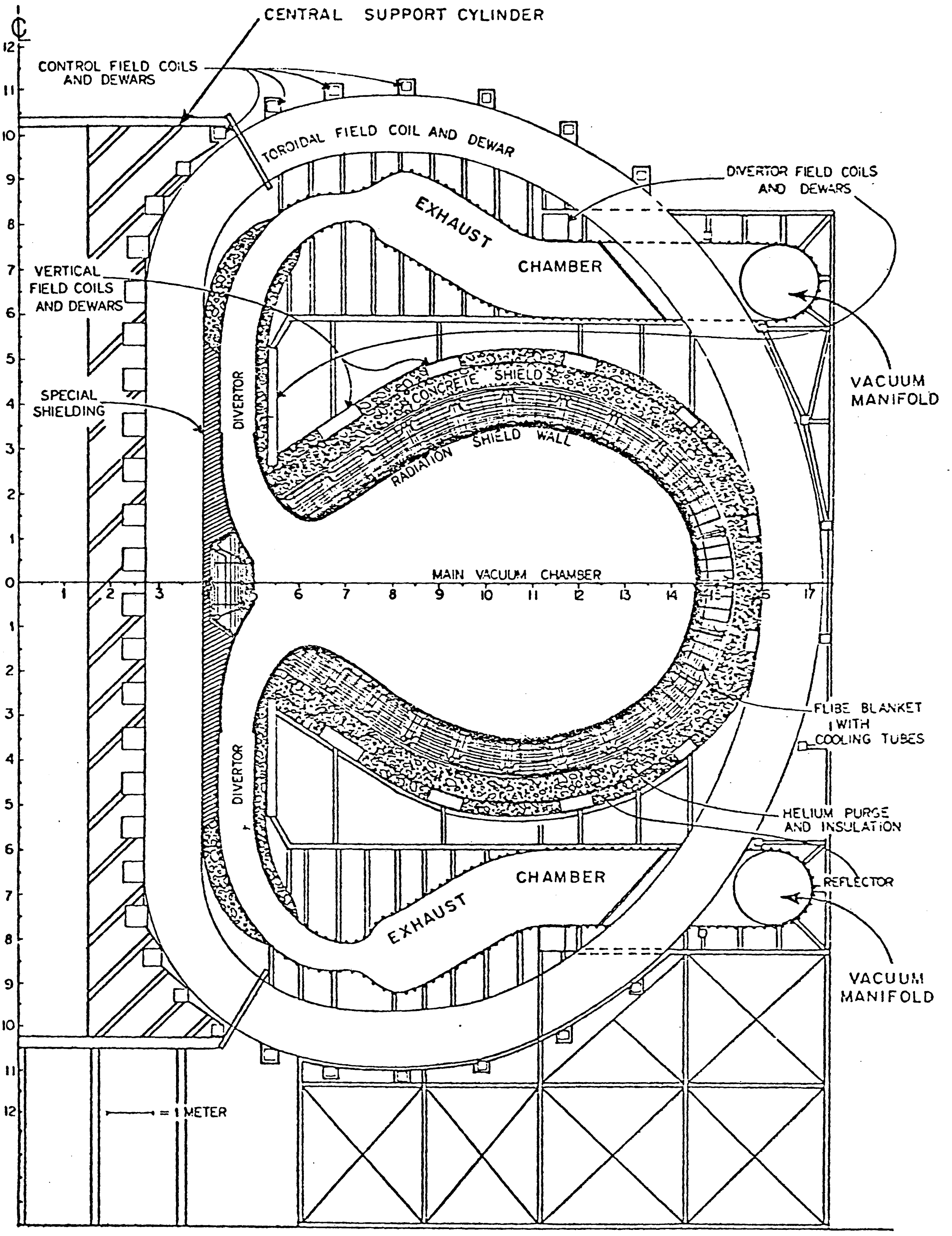


Fig. 1: Cross section of a proposed magnetic field fusion reactor (16).

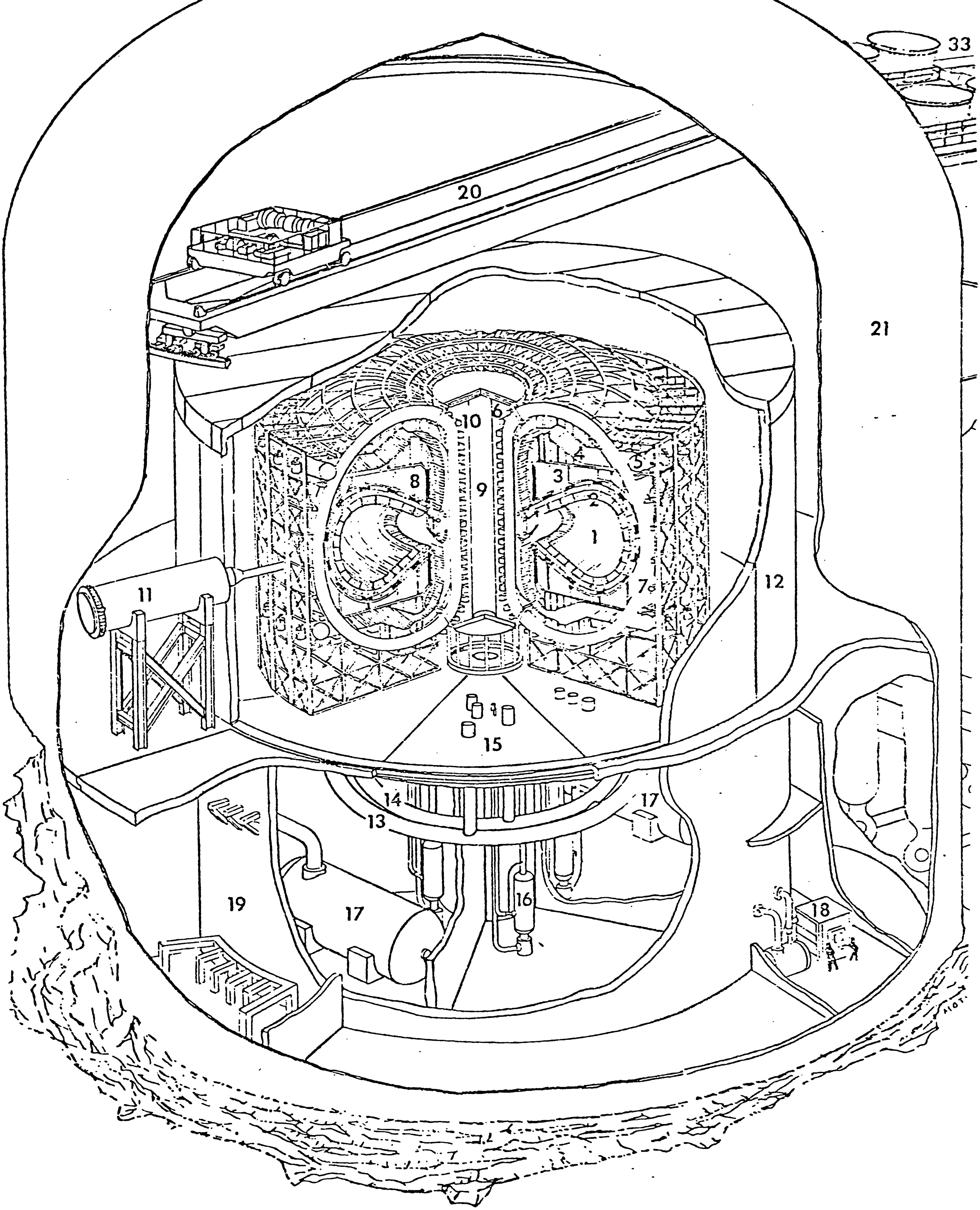
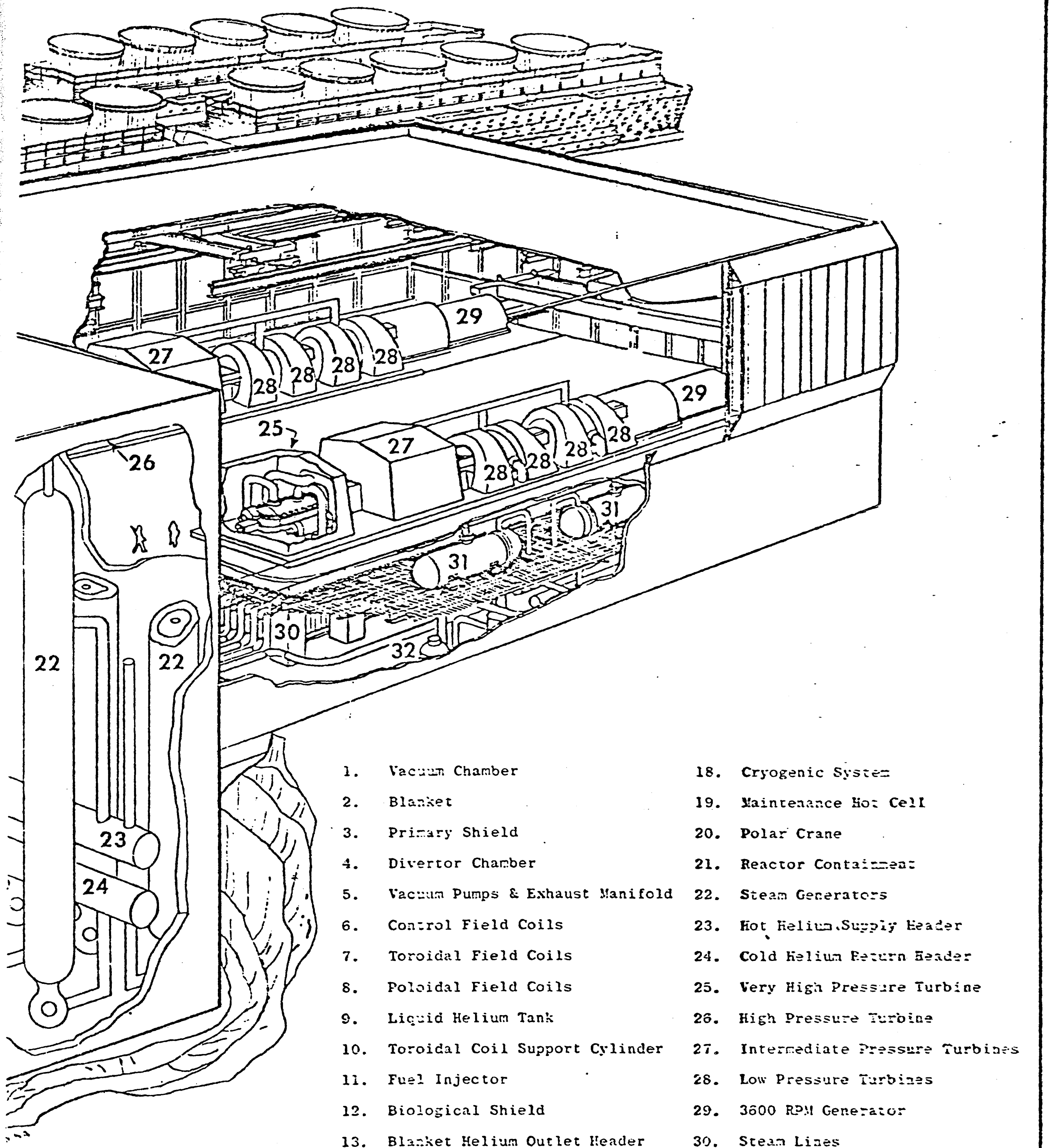


Fig. 2: Cutaway view of proposed magnetic field fusion reactor (16). See also Fig. 3.



1. Vacuum Chamber
2. Blanket
3. Primary Shield
4. Divertor Chamber
5. Vacuum Pumps & Exhaust Manifold
6. Control Field Coils
7. Toroidal Field Coils
8. Poloidal Field Coils
9. Liquid Helium Tank
10. Toroidal Coil Support Cylinder
11. Fuel Injector
12. Biological Shield
13. Blanket Helium Outlet Header
14. Blanket Helium Inlet Header
15. Helium and Flibe Lines
16. Flibe-TF Disengagers
17. Flibe Storage Tanks
18. Cryogenic System
19. Maintenance Hot Cell
20. Polar Crane
21. Reactor Containment
22. Steam Generators
23. Hot Helium Supply Header
24. Cold Helium Return Header
25. Very High Pressure Turbine
26. High Pressure Turbine
27. Intermediate Pressure Turbines
28. Low Pressure Turbines
29. 3600 RPM Generator
30. Steam Lines
31. Feedwater Heaters
32. Feedwater Treatment
33. Cooling Towers

Fig. 3: Continuation of Fig. 2 (16).

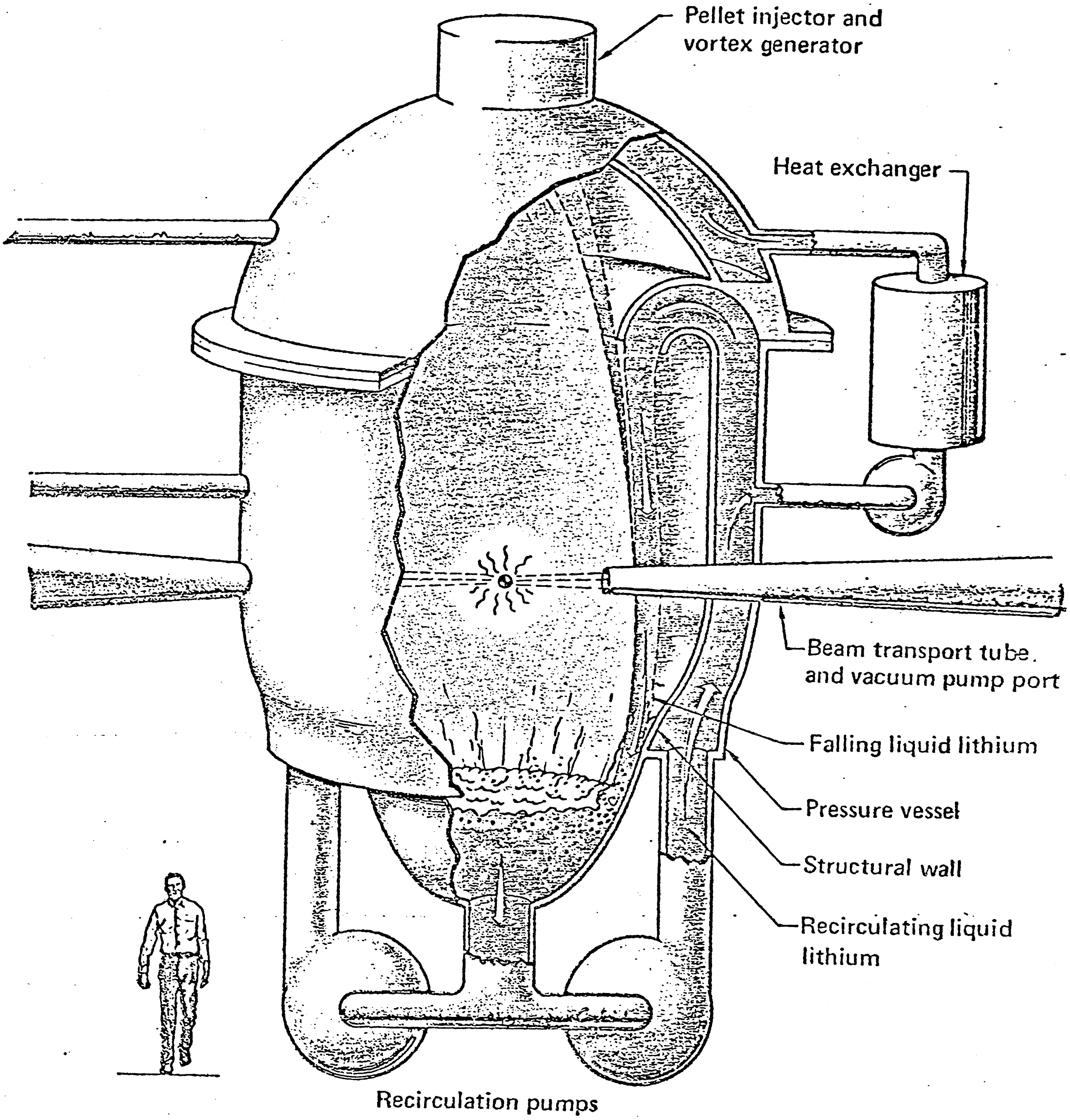


Fig. 4: Proposed laser fusion reactor (14).

however, we shall find more promising prospects if we exploit the cheap hydrogen that may be produced in shore-based fusion plants, whether of the magnetic field or inertially confined variety. Such inexpensive hydrogen can be combined in many ways with other materials in order to produce liquid fuels that could be burned in diesel engines, gas turbines or boilers. Hydrogen can be chemically reacted with carbon dioxide to produce methanol, which can in turn be catalytically converted to gasoline, or kerosene.(5) Hydrogen can also be used in various enriching combinations with low-grade fossil fuels.

The range of possibilities is enormous, and so at this point we must keep our minds open to many eventual applications of fusion power for ship propulsion.

CONCLUSIONS

From the evidence I can gather, I find it hard to believe that nuclear power, in its present form, is likely to be the solution to the long-term energy needs of the world's merchant fleets. Its maritime applicability seems highly limited; and we must face the fact that land-based nuclear power plants may within a few decades exhaust the world's supply of readily obtained fissile fuels.

In another three or four decades we may hope to see the successful development of fusion nuclear power. Fusion power is safer than fission power, and operates on an almost unlimited supply of fuel. In the interim, most nations can be expected to ration fuel oil, giving vehicles priority over stationary users such as electrical generating stations. As oil wells are depleted, and prices go ever higher, we can expect to see oil derived from sands and shale. We can expect to see liquid fuels derived from coal. And there will no doubt be experiments with other sources of energy, such as wood chips and, quite conceivably, a return to sail in some trades.

If fusion power does indeed bring a long-term solution to our energy needs, its initial application to the marine industry is likely to be indirect. That is, shore-based fusion plants may be used to produce cheap hydrogen, which can be used in many ways to help produce liquid fuels suitable for marine service. In short, I believe that ships' engine rooms are going to look much the same thirty to forty years from now as they do today.

EPILOGUE
ON NUCLEAR TERMINOLOGY

We need, it seems, a lexicon
To clarify what we're talking on.
Some find that "fissile" and "fossil" jostle,
While others find "fission" and "fusion" confusin'.
We could avoid such mental friction
If we had words of clearer diction.

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APPENDIX

NOTES FOR TABLES I - IV

1. A more logical comparison would start with identical overall dimensions and allow the deadweight to be derived. The conventional ship is penalized under the approach used here.
2. The reference study(17) assumes round trip bunkers will be taken on at the loading port. I assume round trip bunkers will be taken on at point of discharge. We both allow a five-day fuel oil margin.
3. The reference study(17) uses a specific fuel consumption of 0.477 lbs per SHP-hour. Modern steam plants of 60,000 SHP should be able to do considerably better than that, and especially as reheat cycle, etc. are added commensurate with higher costs of fuel.(4) Ref. 17 does not specify what steam cycle it assumes, but let us consider a reheat cycle with economizer and steam air heater, producing a specific fuel consumption of 0.408 pounds per SHP-hr (185 grams per SHP-hr). I have rounded this up to 0.42 pounds per SHP-hr (191 grams per SHP-hr) to cover less-than-optimum operating conditions. I have also added $2 million to the construction cost (U.S.) in token recognition of a more complex plant. This automatically leads to greater costs of insurance and maintenance and repair because they are estimated as a fraction of first cost. A specific fuel consumption of 0.42 lbs per SHP-hr when used with 54000 SHP leads to a daily at-sea fuel use of 243 long tons or 1611 barrels.
4. The nuclear ship requires five extra men. One is a health physicist. The others are presumably required because of the twin screw arrangement. There is room to argue that the nuclear ship could be safely operated with only one extra man.

5. The reference study assumes nuclear refueling in alternate years taking six extra days (over the conventional ship) each time. I assume an added penalty against the nuclear ship of two days per year because of added complications in carrying out routine maintenance and repair. Needless to say, nuclear plants may be subject to much worse delays because of radioactivity.

6. The reference introduces a special subsidy, "nuclear incentive allowance," which I omit in interest of weighing true economics.

7. Costs are for each of three identical units. I assume the nuclear ship cost includes a 2-year fuel supply.

8. I have allowed an extra $2 million in the conventional ship as explained in Note 3.

9. Non-U.S. construction cost is derived from the 35 percent subsidy used in the reference study.

10. I assume that learning curve benefits will reduce nuclear ship costs by 10 percent.

11. Owner's costs and pre-delivery interest are both omitted.

12. I have cut reference costs in two to convert to non-U.S. levels. I have also added 5 percent to average wages for crew of nuclear ship. The reference uses $79,591 as the average wage per man in 1982.

13. The reference uses $7.55 per man per operating day. I use the same daily cost but assume it will continue over 365 days.

14. The reference estimates M&R costs as $1.229 million for the nuclear ship and $1.084 million for the conventional. I use the classical 2 percent of first cost.

15. Hull and machinery insurance is taken as 1.125 percent of first cost.

16. Forecasting future costs of P&I insurance for nuclear ships is certainly one of the most difficult steps in this comparison. The reference uses $1.25 per ton of deadweight for the conventional ship. For the nuclear ship it uses the same $1.25 per DWT plus a special annual premium of $575,000 for nuclear

16 cont.

indemnity. This is presumably based on some form of government underwriting similar to the Price-Anderson Act. In the interest of making a fair economic comparison I assume no such hidden subsidy. I use the reference's figure for the conventional ship and arbitrarily double it for the nuclear ship. This is admittedly only a guess. I am sure I shall be dodging harpoons on this issue--from both directions.

17. The reference estimates $325,000 per year for stores and supplies for either alternative. I prefer to increase the amount somewhat in the case of the nuclear ship because of the larger crew. I assume that half the cost will vary directly with the numbers in the crew.

18. The reference uses $660,000 per year for overhead and miscellaneous costs for each ship. I have chosen to increase that figure by 10 percent for the nuclear ship. This recognizes greater costs of crew repatriation and higher legal fees appropriate to the nuclear ship.

19. The reference uses $220,000 per round trip for port charges. I assess an extra 25 percent for special precautions, etc. in the case of the nuclear ship.

20. There are no canals in the proposed voyage, hence no canal fees.

21. The reference estimates a need for 4 men in a shore staff servicing 3 ships. I use their figures.

22. The nuclear refueling cost includes drydock charges. It occurs in alternate years. The figure shown is for that cost spread over two years.

23. The annual cost of nuclear fuel is taken as the reference's biannual cost spread over two years.

24. As explained in Note 3, I have changed the specific fuel consumption from that used in the reference. I estimate a fuel rate of 243 tons per day at sea, but accept their figure of 5.32 tons per hour in port.

25. Bunker oil costs are currently running about $12 per barrel or $80 per ton. I have arbitrarily increased oil costs by 25 percent (in constant value dollars) in recognition of probable future trends. This brings the price to $15 per barrel.

26. CRF (capital recovery factor) is used to convert the initial capital cost to a uniform annual end-of-year amount equal in present value to the capital cost. The minimum level will repay the initial investment over the assumed 20-year life with a yield of 10 percent, assuming that the owner need pay no corporate income tax. The numerical value is taken from tables of compound interest.

27. The annual cost of capital recovery is the product of CRF and the initial cost shown in Table III.

28. The average annual cost is the sum of the annual operating cost and the annual cost of capital recovery.

29. The "normal" CRF is high enough to repay the initial investment over the assumed 20-year life with a yield of 10 percent after paying corporate income tax at an effective rate of 35 percent. (The nominal rate would presumably be higher, but would be attenuated by fast write-off and investment tax credits.)

30. The annual transport capacity is from Table II.

31. RFR (required freight rate) is the rate the owner must charge his customer if the owner is to regain his investment at the stipulated yield (after tax). The RFR based on "normal" CRF is probably of more general usefulness because few shipowners can escape paying taxes.

DATE DUE

APRIL 23	1982		