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NUCLEAR MARITIME PROPULSION – WHERE IS IT?

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SYNOPSIS

This is a discussion of what might have been for commercial nuclear maritime, why it was not and what it still may become.

Technology and economics are dismissed as having been thoroughly debated and favourably demonstrated. The discussion develops the theme that the major obstacles to commercial acceptance of nuclear ship propulsion are not technical but cover a range of international and domestic administrative type issues. The administrative issues are discussed and evaluations and potential solutions suggested.

To establish the foundation for the discussion theme, nuclear power as applied to ship propulsion is reviewed from the type of reactor used with various shipboard applications considered and finally an evaluation of nuclear fleets operating today.

INTRODUCTION

Nuclear maritime technology and economics have been debated and discussed for over 20 years – with no doubt about the former and with 100 percent "hindsight" for the latter. Commercially viable nuclear merchant ships could be plying the world's trade routes and saving millions of barrels a day of precious fuel oil. If this is true, then why has it not happened? It is the purpose of this paper to discuss the inadequacies of the past and present and to look to the future with a sincere hope that such a discussion will contribute positively to commercial nuclear maritime success.

In 1955, the *Nautilus* made its maiden voyage, becoming the world's first nuclear-propelled ship. Since then, and under the flags of 6 nations, approximately 250 nuclear propelled ships have gone into operation, with only three of these ships being considered as commercial endeavours. In September 1959 the Soviet icebreaker *Lenin* made its maiden voyage, becoming the world's first nuclear-powered surface vessel. In 1963 the *NS Savannah* went to sea and even though she was a demonstration and development vessel she was the world's first attempt at commercial nuclear maritime. In 1968 the Federal Republic of Germany's *NS Otto Hahn* went to sea and followed and extended the exploits of the *NS Savannah*. Unfortunately, the *Otto Hahn* is the only commercial nuclear ship sailing today, the politically scuttled *Mutsu* has yet to achieve sustained open sea operations and the *Savannah* has been retired.

With this background and the current concern for the future of oil, it is hard to accept that a single ten-year-old demonstration ship represents the sum total of the world's nuclear merchant fleet. If the maritime community had reacted in a similar manner to Robert Fulton's *Clermont* voyage on the Hudson River back in the eighteen hundreds, large fleets of square riggers would still be carrying the world's waterborne commerce.

It is clear that as an international industrial community the maritime has failed to exploit that which is readily available. In order to determine how to overcome this failure it is necessary to explore what might have been, why it was not, and what it still can be. To do so, the types of nuclear power plants investigated and the types of ships considered for the nuclear application must be discussed.

NUCLEAR POWER PLANTS FOR SHIP PROPULSION

The nuclear reactor is simply a source of heat, similar to the furnace of a boiler, the notable exception being that the nuclear reactor can contain enough fuel to operate several years without refueling. The heat generated in a

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nuclear reactor is the result of the fission process within the uranium fuel normally enriched in the fissionable isotope uranium-235.

For over a quarter of a century, many designs and variations of nuclear reactors have been studied, tested and put into operation. All nuclear reactors are designed and engineered to remove the heat from the relatively small reactor by some coolant, transport the coolant away from the reactor where its heat is extracted and put to work by more conventional means, and then return the coolant to the reactor for more heat. Various reactor coolants have been tried such as water (heavy and light), gases, liquid metals and some exotic fluids such as molten salt. Technology to date has resulted in two basic coolants, gas and water, for the world's productive reactors. Water cooling is the more predominant and pressurized water reactors (PWR) make up the vast majority of the world's power reactors.

The PWR system employs ordinary water, highly purified and pressurized to prevent boiling in the reactor coolant loop. For example, a reactor coolant loop operating at a maximum temperature near 600°F may be pressurized in excess of 2000 psi resulting in the loop being at least 50°F subcooled.

It is sufficient to say that the PWR has been settled upon by nuclear engineers throughout the world as the preferred reactor coolant and power conversion system for ship propulsion. The US Navy nuclear submarines and surface ships, the Russian (including their icebreakers), British and French navy nuclear ships, the *Otto Hahn*, the *Mutsu* and the *NS Savannah* are all propelled using this basic scheme with engineering variations to suit the particular application.

For commercial nuclear maritime, two fundamental mechanical layout schemes have been developed for the PWR reactor heat transport and steam generating system. The simplest uses piping to convey heated coolant from the reactor pressure vessel to a steam generator where it is cooled by the process of generating turbine steam with the coolant being pumped back to the reactor for reheating. This system is commonly referred to as a loop or spread-out system and was used on the *NS Savannah* and the *Mutsu*. Over the last 20 years a more compact heat transfer system has been developed in which flow passages within the reactor vessel itself substitute for piping and the steam generators are located within the pressure vessel. This integral reactor is known as the Consolidated Nuclear Steam Generator, or CNSG, the earlier design of which was licensed to the Federal Republic of Germany and is the nuclear system used aboard the *Otto Hahn*.

For over 20 years on-going programmes in the USA and elsewhere have consistently resulted in PWR designs and shipboard applications which demonstrate the potential for commercial nuclear ship propulsion.

SHIPBOARD APPLICATION

It is fundamental to nuclear economics that larger output reactors are required to offset higher capital cost with higher productivity and lower fuel and operational cost. The introduction of nuclear-produced steam for electrical generation resulted in an almost phenomenal growth in plant sizes to 600,000 to 800,000 kilowatt electric (KWe) output versus the 200,000 KWe outputs of the more conventional fossil fuelled plants of the time. Today, electrical outputs of 1,200,000 KWe are common for nuclear generating plants.

At the time the *NS Savannah* was designed with its 22,000 shaft horsepower (SHP) nuclear system, merchant ships of 25 or 30 thousand SHP were virtually unheard of, and the 100,000 dead weight ton plus tankers were still a dream. It was obvious from the beginning that effective and economic use of nuclear power for merchant ship propulsion required the ship designer and builder to think in terms of 60,000 SHP and above. Existing technology very quickly showed that the optimum power train to be considered should approach 120,000 SHP, (the approximate equivalent of 100,000 KWe) and with full consideration to a twin screw propelled ship.

The application of these larger horsepowers was directed first to the dry cargo ship and the containership, for high speed productivity. With Panama Canal considerations, a 120,000 SHP propulsion system would result in a 33 knot containership. For several years design and analysis were conducted with shipowners, operators and builders and numerous reports of performance and economics were made.

A second major application, for which extensive design and analysis were performed, again in consort with owners, operators and builders, was the larger tanker. The philosophy for tanker application was simply higher powers to propel much larger ships (400,000 to 600,000 DWT) at a few knots above the conventional speeds of 14 to 16 knots. Tanker speeds exceeding 20 knots raised the concern for the state of the art technology relative to more efficient hull designs. Therefore, for the tanker applications, it was simply a case of increasing productivity, primarily by brute force, for propelling vast quantities of petroleum cargoes.

A third application considered was the LNG carrier. However, since the LNG carrier itself represented a new and unique technology, it was felt that applying nuclear power should be delayed. Of all the merchant ships investigated, the LNG carrier with its boil-off and large cargo value would be a most attractive application for the high speed productivity offered by nuclear propulsion.

Several speciality applications for commercial nuclear propulsion have been studied and thoroughly analyzed. Applications such as petroleum drill ships, arctic icebreaking service ships as well as arctic tankers, all showed great potential because of their extraordinary high power requirements and/or long times on station. Working with the Canadian Coast Guard, powerful icebreaking cutters have been studied. This application is very attractive relative to extended time on station, increase range of operation, and large power requirements, all needed for successful operation in the hostile environment of the arctic. Decisions to proceed with this project have not yet been announced by the Canadian Coast Guard. Russia's penetration to the North Pole with one of its nuclear icebreakers demonstrated the potential for such vessels.

1970 NUCLEAR FLEETS OPERATING IN 1979

From the late sixties through to 1973, when major programmes for design and analysis of nuclear-propelled merchant ships were in progress, no-one had the foresight to see an energy crisis develop in the middle and late seventies.

The projections of petroleum cost and in particular that of Bunker C fuel oil made in the 1969 to 1973 period were relatively consistent. The most pessimistic of such projections showed Bunker C going from a universal 2.50 dollars per barrel in 1969 and 1970 to maybe 12.00 dollars per barrel by 1990 and over 20 dollars per barrel by the turn of the century; pessimistic projections not readily accepted by fleet operators of the time. Following the October war of 1973 and the ensuing oil embargo, a price rise occurred in Bunker C to over 11 dollars per barrel, fifteen years ahead of the most pessimistic projection of just three years before. Now, five years after the October '73 war, there has been no abatement of Bunker C cost; in fact, a continual rise is expected for the "predictable" future.

If, in the middle sixties, the price rises of 1974 could have been foreseen, would there have been commercial nuclear fleets today? If so, how would such fleets be competing with the existing fossil fuelled containerships and tankers plying the world's shipping lanes? Many would say the answer is "no", because nuclear fuels have also quadrupled in price. What they fail to recognize is that while both fossil and nuclear fuel costs have quadrupled over the same period, the difference between them has also quadrupled.

Assuming that commercial nuclear ships, both containerships and tankers, started operating in 1970 and, by February 1979, large fleets of both are plying the seas, their fuel cost in today's environment can be analyzed.

Most in the maritime community have a good working knowledge and understanding of ship capital cost and operating costs such as insurance, crewing, subsistance, maintenance and the like. What most do not understand is the relative cost merits of fossil fuels and nuclear fuels. In the maritime, Bunker C fuel costs are usually related to dollars per barrel or dollars per tonne with consumption bench marked to tonnes per day of open sea operations. In the nuclear industry, nuclear fuel costs are usually referenced to mils per kilowatt hour. For consistency both Bunker C and nuclear fuel can be related to mils per shaft horsepower hour (mils/SHP-HR). Assuming Bunker C at 336 pounds per barrel and specific fuel consumption at 0.48 to 0.50 pounds per shaft horsepower hour for an efficient boiler, then:

$$\text{For Bunker C: MILS/SHP-HR} = \left\{\frac{\$}{\text{BBL}}\right\} \frac{0.48 \times 1000}{336}$$

$$= 1.43 \left\{\frac{\$}{\text{BBL}}\right\}$$

and in 1969 and 1970 when Bunker C was at 2.50 $/BBL its fuel cost was approximately 3.6 mils/SHP-HR. At that same point considering the cost of ore, uranium conversion, enrichment, fabrication of fuel assemblies, cost of investment during operations, refuelling and reprocessing, the cost of a two-year nuclear core equated to approximately 1.5 mils/SHP-HR in the 80,000 to 120,000 SHP range. Therefore, in 1969 and 1970, the nuclear fuel application offered about 2.1 mils/SHP-HR savings on fuel cost.

In today's market, at 11 and 12 $/BBL, Bunker C fuel cost is 15.7 to 17.2 mils/SHP-HR. Nuclear fuel costs are estimated in the 7 to 8 mils/SHP-HR range, having escalated more rapidly than Bunker C cost. However, the nuclear fuel application of today offers almost 9.0 mils/SHP-HR savings on fuel cost.

Applying these fuel costs to today's operations, i.e., fossil fuel cost at 17.2 mils/SHP-HR and nuclear fuel cost at 8 mils/SHP-HR, consider a nuclear and a fossil fuel containership, each at 120,000 SHP and 33 knot service speed operating over long trade routes with the equivalent of 70% open sea operations at rated service speed. When at sea, the fossil fuel ship will consume over 650 tons of fuel per day at an annual fuel cost of almost 13 million dollars. For the same situation, the nuclear ship's annual fuel bill will be less than 6 million dollars. A gross savings of some 7 million dollars per year.

Applying today's fuel cost to tanker operations is not as direct as for containerships of similar performance and capacity. For tankers, the optimum speed and power for a given size ship differs for nuclear and fossil fuel considerations. Therefore, for two 600,000 DWT tankers on a Persian Gulf to USA or Western Europe route, apparent optimums are as follows: the fossil fuelled tanker at 55,000 SHP and 14½ knots service speed and the nuclear fuelled tanker at 100,000 SHP and 19 knots service speed. In one average year the fossil fuelled tanker will deliver 2.70 million tonnes of crude oil at an annual fuel cost of 7.30 million dollars. In the same average year the nuclear tanker will deliver 3.64 million tonnes of crude oil at an annual fuel cost of 6.12 million dollars. Using Required Freight Rate (RFR) as a measure of merit, the fuel component of the total RFR for each tanker is: 2.71 dollars per tonne for the fossil fuelled tanker and 1.68 dollars per tonne for the nuclear fuelled tanker.

From the preceding, annual gross fuel savings resulting from nuclear ship propulsion are significant for both large containership and tanker operations in today's environment. However, it is not the authors' purpose to present total economics, that is, net fuel savings relative to capitalization, crewing, insurance, etc. Their purpose is simply to demonstrate, relative to fuel only, the extreme escalations of both fossil and nuclear fuel costs since the embargo of 1974 and the resultant increase in savings for the nuclear fuel application. Therefore, the nuclear fleets of "1970" would be more competitive today than could have been envisioned in 1970.

ISSUES AND OBSTACLES

Nuclear power for ship propulsion and its commercial application has been discussed. As stated in the introduction, with great hindsight, the authors have touched on the potential of superior economics of operations by fantasizing what might have been. They have not yet addressed themselves to the reality that commercial nuclear fleets do not exist. What were the issues facing the maritime community for commercialization of nuclear ships in the 1965-1970 period and today?

The issues that were major obstacles to the advent of nuclear maritime five and ten years ago still exist today. In some cases they are even more formidable. To initiate now new programmes to analyze performance and economics or to optimize designs would be as fruitless today as it has been in the past when the issues were not technical or economical. If commercial nuclear maritime is ever to be a reality, then the non-technical, non-economic issues of the past must be addressed, that is, the political and administrative issues that nations continue to bring upon themselves.

Normally, one would expect to identify the major issues or obstacles and then establish a priority for such issues. However, the establishment of a priority is extremely difficult when one attempts to address the issues or obstacles related to commercial nuclear ships. Anyone or any group interested in the use of nuclear power for commercial ships immediately encounters the age-old adage of the chicken and the egg – which came first? Thus, those concerned with port entry say, "Why resolve port entry problems when there are no nuclear ships," and those concerned with building and operating ships say, "We cannot embark on a ship programme until we are confident of free access to the major ports of the world." It appears to the authors that the attitude just described has permeated any effort to establish a commercial nuclear fleet. Obviously, such an attitude must be dispelled if a viable fleet of nuclear-powered commercial ships is ever to exist. It is to be hoped that this paper might contribute something toward a better understanding of the major problems:

- Port Entry
- Indemnification or Insurance
- First-of-a-Kind and Start-up Costs

Port Entry

For several years, many very talented people have worked extremely hard on a document that is usually referred to as the "Brussels Convention." This document is quite complicated but, in essence, is a description of an international agreement which, when accepted by a significant majority of the countries in the world, would permit nuclear-powered commercial ships to operate in the major ports of the world. The intent or purpose of the document should be of significant interest to mankind in general but in today's environment, the probability of ratification of such a document is practically nil. However, there is a relatively simple solution to the port entry problem which does not in any way relate to the Brussels Convention document. The solution is the same as that employed in conjunction with the *NS Savannah* and the *NS Otto Hahn*. Interested nations can negotiate bi-lateral or multi-lateral agreements that will provide nuclear-powered commercial ships with free access to the major world ports. One can expect to encounter opposition. Imagine the reaction in California to newspaper headlines that a nuclear-powered commercial ship will enter the harbour at San Francisco tomorrow. Yet, nuclear-powered ships operate there and in many other major ports on a regular basis. Their presence for the most part is unnoticed and/or ignored. Such operation of nuclear-powered ships has been taking place for over 20 years now, and one cannot identify a single incident that involved any physical harm to any individual or, for that matter, any other living animal. No other energy source has a comparable record.

Indemnification or Insurance

Without question, the safety record of the nuclear industry is outstanding. However, no prudent business can afford to engage in nuclear activities of any type until there is sufficient protection in the unlikely event of a nuclear incident which, hypothetically, might involve thousands of people. Newport News Shipbuilding or Babcock & Wilcox will not issue a single drawing or cut one steel plate for a nuclear-powered ship without adequate protection similar to that available in the US today via the Price-Anderson Act. This Act, as originally conceived, included a Government-imposed limit of liability and Government insurance to cover that amount of insurance not available in the normal insurance market. Obviously, there is existing precedence in the US to solve this problem. One simply uses similar provisions of this act for US flag ships on the high seas. There has never been a law in the USA which provided for private US flag ship owner-protection relative to limiting nuclear liability, as has been the case for land-based electrical nuclear generating plants. The *NS Savannah*, Government-owned, was covered by special legislation incorporating the ship by name under the Price-Anderson nuclear indemnification act. The authors' is an over simplification but quite practical and reasonable. Furthermore, legislation based on the knowledge gained from Price-Anderson has been drafted and introduced to accomplish the same. This proposed legislation lies dormant because there are no nuclear-powered commercial ships.

As with Port Entry, limiting nuclear liability requires a minimum agreement of two. *The country of origin*, the flag state, must be fully receptive to the development and construction of nuclear ships with a political atmosphere of full support. *The trading nation*, other than the one with the nuclear ships, must also be receptive to nuclear maritime and again with favourable political support. Together these nations must agree on the where with all to make nuclear maritime viable. It would do no good to have the flag state establish a limit of nuclear liability, of say 150 million dollars, but have its trading nation require 500 million dollars or worse, unlimited liability. We have seen this happen, with the trend being that the country with the nuclear flag going for the lower more reasonable limits and the country without nuclear flags demanding the more unreasonable limits.

First-of-a-Kind and Start-up Costs

Almost any strong, well-managed company will accept normal business risks and generally will accept very high risks whenever the potential return is comparable. However, the risks associated with the procurement of nuclear-powered ships (herewith reference to the situation in the US) are significantly beyond those acceptable to any prudent businessman. The current regulatory requirements, the continuous upgrading and modification to those regulations and the personal influence associated with the interpretation and implementation of the US regulatory requirements all but eliminate any ability to predict a ship delivery date with any reasonable degree of accuracy. Those regulatory requirements and their implementation share with industry and operators the major credit for the outstanding safety record for which the US can be justifiably proud. Nothing should be done to tarnish that safety record, however, any reasonable and realistic government will readily agree that such stringent rules or regulations, which are constantly undergoing change and upgrading, constitute abnormal business risk. Any responsible government should be ready and willing to assume these abnormal risks in support of a modern merchant marine. There is no legislation or appropriation in the USA offering financial encouragement for private investment in nuclear maritime, as was the case for land-based electrical nuclear generating plants.

Proposed legislation has been drafted to provide the first-of-a-kind and start-up costs for nuclear-powered commercial ships in the US. The legislation is not unique and does not involve unusually large sums of money. In fact, invested 50% of the required funds have probably been invested to protect the breeding grounds of a so-called wide-mouth frog in conjunction with one project in the US. However, the proposed legislation gathers dust since there is no real customer for the nuclear-powered ships. An acceptable customer will have to be a major oil company or someone with a very firm commitment from a major oil company. It appears that the risks involved are no greater than those experienced every day by all major oil companies. But, are the potential returns comparable to those normally expected, or are they commensurate with the risks?

THOUGHTS FOR THE FUTURE

Over the past five years, two of the most consistent supporters of commercial nuclear ships have been S Esleeck of Babcock & Wilcox and A Winall of Newport News Shipbuilding. They have passed through the doors of many major corporations, practically every government or regulatory agency in Washington D.C., and quite a few doors in other countries. In almost every instance, at some point it became apparent that they were suspects to a certain degree. They were attempting to promote nuclear power as a means of generating business for their respective companies. There has never been a really strong "champion of the cause" from a responsible government agency or a major corporation associated with the operating or user end of the maritime industry. The authors seriously doubt that they or others like them will ever put forth a similar effort again unless that so-called "champion" appears.

The real problem to be resolved is far more encompassing than anything touched on to date. In each of the three major obstacles previously referred to (Port Entry; Indemnification; and Start-up Costs), one word is vital – *people.* The primary port entry problem is a tremendous fear by the average citizen of the particular community. The indemnification problem centres around a protection for and a protection from people. The first-of-a-kind and start-up costs are necessary because regulatory agencies are over-sensitive to the reactions of people.

Acceptance of commercial nuclear power by the people of the world has been a very cyclic affair. From the mid-fifties to the early seventies it was a great "White Hope" with universal acceptance for cheap, safe and reliable power. Economics, safety and reliability have not changed, in fact they have improved but a small, vocal minority, so-called purveyors of doom, have been successful in raising such doubts that general acceptance by the people of commercial nuclear power is in question. This is not to say that there are not those who have honest legitimate concerns. However, such concerns can be eased if not eliminated by honest and open discussion.

Until the general public has been educated on a world-wide basis so that major fears have been dispelled and the large majority are in their respective comfort zone with nuclear power, nuclear-powered commercial ships will not become a reality. And any other type of nuclear power plant faces a similar problem. The solution is an extensive educational programme conducted professionally and continuously throughout the world, presented in simple terms and, most of all, one that is perceived by the large majority to be sincere and in the best overall interest of the people. This problem is *most* formidable and very little is being done to resolve it. The authors suggest the immediate establishment of the organization required to resolve the very serious people problem or that nuclear power as a potential source of power for commercial ships be discarded.

In preparing and researching this paper, the authors contacted some of the most prominent people in government and in the maritime international community and solicited their thoughts on commercial nuclear maritime. Most of these people have been very generous in sharing with them their years of wisdom and experience in this field and this discussion has reflected some of their major concerns as presented to the authors.

Discussion

DR J COWLEY, (Department of Trade) opened the discussion and congratulated the authors on a paper which, quite sensibly, had left aside discussion on technology and economics which had already been fully debated on so many occasions. He did not revert to those considerations but preferred, like the authors, to look to the future and the problems that had to be faced if nuclear-powered merchant ships were to be accepted. Indeed, it had been suggested that he should deal chiefly with the developing IMCO code for nuclear merchant ships.

Dr Cowley agreed with the authors that it was the attitude of people, and not technological problems, which inhibited the adoption of nuclear propulsion. He believed that people's attitude towards science and technology had taken a step backward since the 1960s. For example, when the nuclear ship *Savannah* visited Southampton in 1964, people from all over the UK queued for the privilege of just looking into the engine room. A major public relations exercise was now needed to put across the true facts regarding the use and safety of nuclear ships.

The principal problems lay with the acceptance by the public of the thought that a mobile, nuclear power plant could be properly sited in a populated area such as may surround many dock areas of ports throughout the world, since so much resistance was encountered in even the remote siting of some nuclear power stations. Shipowners were unlikely to consider building a merchant ship that was not capable of world wide trading without the protracted bi-lateral negotiations currently required in order to obtain port entry of nuclear ships.

As a traditional maritime trading nation, the United Kingdom was a strong advocate of the free passage of shipping and, as IMCO had made provisions for the use of nuclear merchant ships, the UK Administration considered itself under an obligation to accept them into its ports. It was UK policy that no restriction should be placed on the right of innocent passage of a nuclear ship through its territorial water.

Nevertheless, there were certain requirements which had to be met when a nuclear ship entered a UK port. Those were covered in the "Report of the Committee on the Safety of Nuclear Powered Merchant Ships" (Cmnd 958 published by HMSO). Amongst those requirements was the provision of high level expert advice for the Port Authority, with whom executive responsibility for dealing with any possible emergency within the port confines rested. The Port Authority was required to establish a Safety Panel, which should include a representative of the Port Authority as Chairman and a Department of Trade Surveyor. The Master of the ship or one of his senior members should also serve as a member of the Panel which should also include a health physics expert and other experts as may be deemed necessary. The Panel would advise and assist the Port Authority on matters affecting the safety of the port, and in taking decisions and initiating action in the event of an emergency. Whilst the Department of Trade Surveyor would provide an immediate link with the Government Departments concerned.

As was usual with a land-based reactor, there should be a standing local Liaison Committee whose main function was to create administrative machinery for the protection of the population in the event of a serious incident. The Liaison Committee should produce, well in advance of the arrival of the nuclear ship, plans for dealing with any emergency which could arise from her presence in that port. The plan would be complementary to the internal Port Emergency Plan worked out by the Safety Panel.

A further requirement, which could cause difficulties, was that berths for a nuclear ship must be such that it could be towed in an emergency from the port within 12 hours at most. In order that a nuclear ship, which has been berthed or anchored, may be able to move in any emergency, sufficient tugs and, if required, a pilot should be available on call at short notice at all times. The requirement for tugs to be available at short notice was sometimes particularly difficult to fulfil.

The 1960 SOLAS Convention contained a chapter of regulations applying to nuclear ships, and an annex to the Convention contained recommendations relating to their construction and operation. Those were also contained in the 1974 SOLAS Convention, and a resolution at the 1974 Conference recommended that the relevant provisions should be revised. That had been proceeded with and an IMCO working group with delegates from 12 countries (including the United Kingdom) and four organizations having observer status at IMCO, had completed a draft "Code for the Safety of Nuclear Merchant Ships", but it was not expected to have other than recommendatory status.

Safety consideration in the use of Ports and Approaches (as opposed to those of the ship itself), by Nuclear Merchant Ships was the subject of an International Atomic Energy Agency publication developed jointly with IMCO as publication No 27 in the IAEA Safety Series. That recommendatory guide published in 1968, was also to be revised during 1979 by the IMCO group working jointly with IAEA. It had been suggested that those two documents mentioned could be published together as a single Code, but that was yet to be decided.

The Code of Safety for Nuclear Merchant Ships in its present draft form was quite a comprehensive document (175 pages), dealing with general safety principles of PWRs through the stages of design, construction, manning and training, operation, and survey, as well as, in certain circumstances, the decommissioning of the reactor plant after an accident. While in itself, it introduced little change in the state of the art, a number of contentious matters were discussed and some imponderables remained for further development, but it was hoped that a ship built to the Code would be more readily and confidently accepted into the ports of nations who themselves might not have well-developed expertise in the technology, as well as setting an agreed standard for those who have.

Without detracting from the importance of the ship's code, Dr Cowley expressed the view that well-developed port entry requirements could have an even greater influence on the general acceptance of nuclear merchant ships into all ports of the world, but might well be a more difficult task than the development of the ships code, in view of the vastly divergent conditions found in ports and approaches globally. It was possible that operation in narrow waters and canals would be considered for inclusion in the revised guidelines, as they had not been dealt with previously.

Much effort would yet be expended on those two documents and it was hoped that it would be rewarded by more easy acceptance of nuclear merchant ships as conventional world traders.

MR H A MARTIN, MI Mech E (Atomic Energy Research Establishment) did not think that there were many professional people with experience of the nuclear or marine environment who would take issue with the general message of the paper. The real problems concerned international agreement on issues which were almost unique to nuclear merchant ships. Such issues took a very long time to process and it might be argued that it was never too early to start. There were, however, a number of important factors which influenced judgement on both the timing, and the intensity, of the effort:

1) Land-based nuclear installations would continue to dominate the thinking regarding issues such as fissile material costs, processing, safety, environmental and social acceptability. Until such times when the latter two could move into a more favourable climate of public opinion, any progress on the general acceptability of nuclear ships would be exceedingly slow.
2) Because of the 1974 oil price increases, and also present tanker accidents, there appeared to have been a reconsideration of the trend towards massive oil tankers and very fast container ships, both areas of potential advantage to nuclear propulsion.
3) Whilst acknowledging that oil supply and price could be influenced, from time to time, by political crises in certain areas of the world, the general concensus of long term forecasts of world resources of liquid fuel appeared to have shown some increasing optimism. The availability of liquid fuel for premium use in, for example, transportation up to the year 2020, and perhaps beyond, was now readily suggested. Admittedly, forecasts of possible prices at such distant dates were not easy to agree upon and might easily create an overwhelming case for nuclear propulsion in some ships, but the time was nevertheless so distant that it became difficult to generate or justify much enthusiasm for immediate action by government bodies.

Despite his apparent pessimism, Mr Martin wished to make clear that he was a supporter of the concept of nuclear propulsion for large ships, and that he had been concerned with aspects of the design and use of small reactors intermittently since the late 1950s. In view of the encouragement from the Chairman for interactive discussion, he added two further points to his contribution.

Regarding the reference made by Mr Clements about the high capital cost of the nuclear vessel in the study carried out by the Shell Company: Mr Martin was a member of the Programmes Analysis Unit team which carried out economic cost benefit analysis studies in 1975/6 on a number of ships with alternative propulsion units. To the best of his recollection the capital costs of the nuclear ships lay between 30% and 40% in excess of their conventional counterparts (tankers tending to the upper and container ships the lower end of the differential).

He finished with a question to Mr Winall: in the presentation, he had mentioned that over 250 ships had operated across the world for many years with nuclear propulsion units and had built up a safety record second to none. It was admitted that almost all of those ships had been manned by highly-trained and disciplined military crews. He was interested to have Mr Winall's comments on the possible difficulties and the safety implications for nuclear-propelled commercial ships trying to operate with less highly-trained and disciplined crews.

MR D J NICHOLAS, BSc, C Eng, FRINA (Lloyd's Register of Shipping), said that the authors remarks regarding their attempts to interest owners, operators and government agencies in the future of commercial nuclear ships had struck a sympathetic chord with a number of people who had very similar past experiences with potential UK operators.

Those of them who were associated in some way with those heady days of the early sixties, when they felt they had proved the technical feasibility of commercial nuclear ships, had, often wondered what the position would be now if a significant number of commercial nuclear ships had been built and were operating today. Had a great deal been lost due to that apparent lack of enterprise and initiative?

While he agreed with the authors that in that intervening period much could have been done to dispel the misgivings of the general public and the, perhaps, over-cautious approach of regulatory agencies, he was not at all convinced that the idea of commercial nuclear ships overall, would have been sold if they had proceeded on the basis of the ship designs which were being considered at that time, namely conventional dry cargo ships of about 18 to 20 knots and 60,000 dwt tankers.

He now realized that using such examples, it was claimed at the time that economic parity between nuclear and oil-fuelled ships could be achieved. As far as he recalled, however, at least fifteen identical ships and reactor systems had to be ordered and high, open sea utilization guaranteed, before one could break even. To show a more favourable comparison, it was necessary to take advantage of the high power available from a reactor and that could obviously only be done by designing ships which were very much larger and faster than those currently in service.

Given such alternatives, it was not surprising that, owners showed a reluctance to order nuclear-powered ships. In his opinion, again with the hindsight of the authors, he thought the viability of non-naval nuclear ships could have been established, had greater effort been made on the application of nuclear power to ships such as ice-breakers, submarine tankers, barge carriers and other unconventional vessels.

Having reflected on what might have been, the position today had to be considered. It was surely very different from those early days. Advances in ship design had enabled ULCC to be built and large, fast container ships to become the norm. Those were the very ships hardly envisaged at the time when the 60,000 dwt tanker ruled supreme. Perhaps for the benefit of those like himself who had been out of the nuclear scene for some years, the authors could let them know if similar major advances had been made in nuclear technology which made reactors more attractive for shipboard application.

To give a complete picture of the current situation, taking into account the technical advances on all fronts and the apparent favourable comparison of nuclear and fossil fuels costs detailed by the authors, it would be most interesting to see an up to date comparison of operational costs of nuclear and conventional ships. While he realized it was not the authors' purpose in the paper to discuss the comparison in absolute terms, he felt that such a comparison would make a very useful addition.

Finally, he wished the authors well in their continued waving of the nuclear flag. Events were moving in their favour and, although the enlargement of the nuclear merchant fleet would still require either some form of governmental or international financial support, there was no doubt that the picture looked far more attractive today than it did fifteen years ago. It was to be hoped that the progress in the education of the public at large, could match the progress which would no doubt be made on the technical side.

MISS E J MacNAIR, (Ministry of Defence) commented that a nuclear ship could be an admirable means of shuttling rapidly back and forth across the Atlantic or Pacific Ocean but, being unable to enter harbour at either end, it was rather analogous to Concorde with few airports allowing it to land.

However, unlike Concorde, the nuclear ship was not only not a consumer of conventional fuel, but it could even be a producer of fuel: part of the reactor power could be used to electrolyse seawater and produce hydrogen, which could then be used to fuel self propelled barge containers that could load and discharge the cargo while the parent ship lay offshore.

The nuclear ship studies all seemed to concentrate on the heavy end of the business, the large tankers and container ships, on the assumption that passengers, mail and perishable goods would continue to be carried by air. Surely by the turn of the century, with petroleum fuel becoming increasingly scarce and expensive, sea transport would once again be competitive with aircraft for those premium cargoes? She asked Mr Winnall if he considered that the fast passenger and mail liner could be an attractive application for nuclear propulsion in the long term.

LT R F CHEADLE RN, asked questions which fell into two categories, one technical, the other a matter of policy.

Firstly,, he asked the authors to outline the benefits of an integral steam generator when the vast wealth of experience and safety justifications had been based on the loop system. They had stated that the battle to be won was largely one of public support and the impressive safety record of reactors afloat rested almost entirely on the loop concept.

Secondly, continuing the "education of the general public' theme, one of the most emotive issues was the subject of radioactive waste disposal. What were the proposed users of fuel doing to assure the public that that aspect of a nuclear programme would not be a problem?

MR C D FODEN BSc (Eng), MIEE (FEC Reactor Equipment Ltd) was particularly interested by the authors' slide of the CNSG.

It reminded him of the earlier development of the UK *Magnox* reactor, in which the coolant loops were eventually replaced by a package of boilers placed round the reactor core in a common pressure vessel, as at Wylfa NPS.

His question related to the reactor coolant pumps on CNSG which if he had understood correctly, had replaced the earlier jet pump by a rotary pump housed within the vessel. He wished for details of the pump drive in the following.

1) was the pump drive shaft brought through the SG vessel wall?

2) was the drive a fixed speed one or a variable speed?

3) was the pump drive from a steam turbine or from an electric motor?

In addition, he wondered whether, as was the case of the civil PWR, the largest motor/turbine auxiliary drive on the installation was the main feedwater pump, or whether it was the reactor coolant pump. He asked if the authors could compare the powers of those drives on a nuclear ship.

LT D JOHNSTON RN, said that the authors had concluded that the most important action to be taken in the future was to educate the population in the uses of nuclear power. He agreed that the nuclear industry generally was continually defending itself against criticism by agressive conservationists rather than taking a firm stand to promote itself. He asked what Mr Winall's ex-company had done in the past, and more importantly, what it, and himself, would do in the future to interest people in the benefits of nuclear power.

No reply had been received by the authors at the time of publication. Should a reply be received it will be published as a supplement.

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