

## Studying the feasibility of Nuclear Propulsion in Commercial Shipping

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### **Abstract:-**

Some 600 or so nuclear reactors are operating in the world today of which approximately one-third are operating at sea. The world's first nuclear powered merchant ship the N.S.Savannah was built as an exhibition ship, with sweeping lines, and quite luxurious passenger amenities not to be found on a conventional dry cargo ship. Cargo stowage was always difficult in hold space defined by lines of such elegance. She successfully met the requirements she was built for. Within the last few years several factors have changed, generating renewed interest in nuclear propulsion for merchant ships, for example recent papers concluding that the adoption of nuclear propulsion for high speed container ships is technically feasible and could be commercially more profitable than conventional container ship. This paper aims at raising hopes among people regarding the onset of nuclear propelled commercial ships in the near future.

### **Key Words:-**

Nuclear powered ships, Feasibility study, Commercial, Technical, Safety.

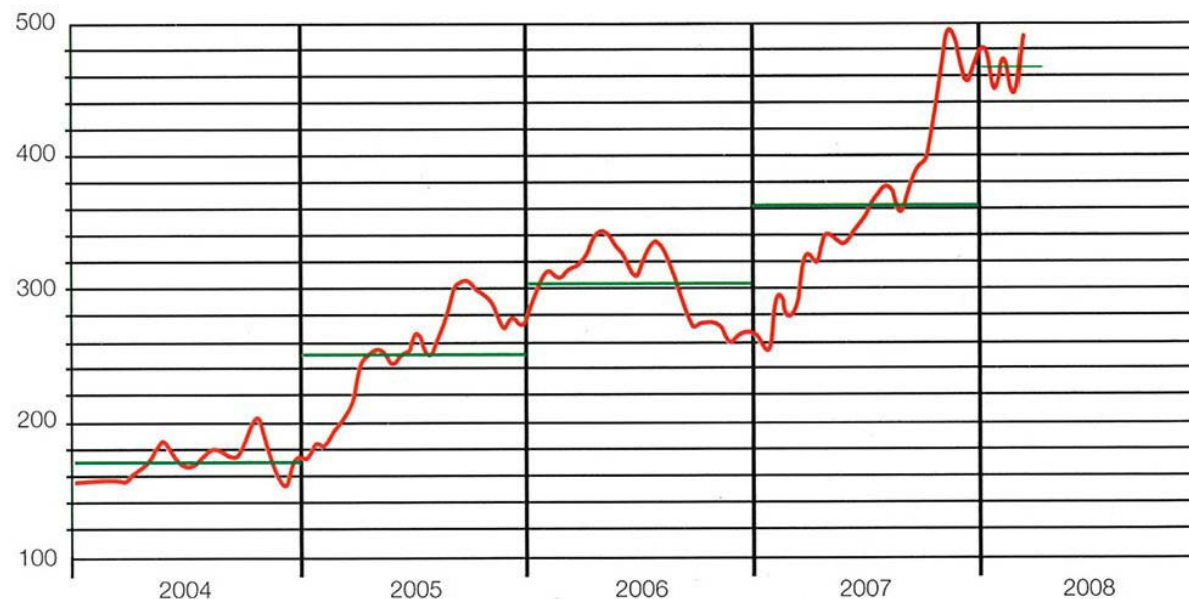
### **Introduction:-**

This is what some eminent names in the shipping industry as well as in the world have got to say:-

- “We believe that that as society recognizes the limited choices available in the low carbon, oil scarce economy.....we will see nuclear ships on specific trade routes sooner than many anticipate”. This prediction came from CEO Richard Sadler of British classification society Lloyd's Register as he announced a research program to investigate nuclear powered commercial ships on 15<sup>th</sup> November 2010.
- In a recent study, Babcock International Group's Marine Division sought to determine the commercial feasibility of utilizing nuclear power for the main propulsion and auxiliary power generation on board an LNG carrier. “The study indicates that particular routes and cargoes lend themselves well to the nuclear propulsion option, and that technological advances in reactor design and manufacture have made the option more appealing.” Said David Dobson , commercial projects director for Babcock's Integrated Technology.
- U.K. governments memorandum for decarbonising Britain by 2050 suggests “building and maintaining a new fleet of nuclear powered container ships and passenger ships”.

The total container traffic within the United States for the six year period from 2000 to 2005 increased by approximately 50%, growing from about 28.5 million TEU to 40 million TEU. Worldwide container shipping is also growing at the same rate. Total movements are also expected to be more than double in the next ten years. The bulk of these goods are transported by merchant ships that burn diesel fuel to propel them through the water. With the cost of crude oil rising to record highs, the cost associated with operating these ships has been skyrocketing as well. A plot of the cost of a barrel of crude oil from 1988 upto 2008 is shown below:-

Bunker price, US\$/tonne  
380cSt HFO



The significant rise in bunker prices in recent years is illustrated on this chart, which shows the average price of 380 cSt heavy fuel oil at various ports around the world from 2004 to 2008; the green bars indicate the mean price for each year

Source: Marine Propulsion, August/September 2008

The rising cost of fuel has resulted in shipping companies either operating their fleet of ships at lower speeds to keep costs down or making fewer trans-oceanic transits. Both of these choices have the obvious effect of decreasing the speed at which goods ultimately make to the consumer.

It is important to note that shipping also releases pollutants into the atmosphere as the ships burn the fuels needed for their propulsion. It has been estimated that shipping is responsible for approximately 14% of the emissions of NO<sub>x</sub> from fossil fuels and 16% of the emissions of SO<sub>x</sub> from petroleum uses into the atmosphere worldwide. It is therefore not surprising that countries are passing legislation that will require ships to reduce their emissions. The cost of reducing these emissions is being paid by the ship owners, meaning that the cost to ship owners to operate their fleet of ships could rise even further. Other restrictions are also set to go into effect at some of the major shipping ports in an effort to clean up the air around these ports. For example, in 2008, the ports of Long Beach and Los Angeles mandated that the top speed of advance for all ships either coming in or out of the port should be no more than 12 knots whenever the vessel is within 40 nautical miles of the port. Furthermore, these same ports require all ships to burn cleaner fuels when within the same land limits, namely .

2% sulfur marine gas oil. The previous land limit was only 20 nautical miles from land. Taken together, these issues makes the search for a cleaner means of ship propulsion very important.

The fundamental objective of this conceptual design is to show through simplified engineering analysis that a nuclear reactor can be used to propel a modern day cargo vessel without significantly affecting the cargo carrying capacity of the vessel and also to investigate the economic validity of nuclear propulsion for merchant vessels.

### **History:-**

#### **Merchant Cargo Ships:-**

The ship, the N.S. Savannah, was authorized by the congress of United States in july of 1956. The ship was to be the first of several nuclear powered merchant vessels under president Dwight D. Eisenhower's atom for peace initiative. The N.S. Savannah was to be a joint venture between the Maritime Administration (MARAD) and the atomic energy commission (AEC). Since extensive information is readily available for N.S. Savannah, it served as a model for much of this project.



The N.S. Savannah.

**The Proposed Ship:-**

The baseline ship used for this project is Emma Maersk. It is the suited example to be taken as container ship usually travels faster than any other ships and also this is a big ship so large amount of power is required. So installation of nuclear reactor on this ship will be most appropriate.



## Emma Maersk

LOA :- 397 meters

Beam :- 56 meters

Depth (molded) :- 30 meters

Displacement :- 120,000 LT

Cargo Capacity :- 11,000 + TEU

Crew :- ~ 13

Cruising Speed:- 25 Knots

Maximum Speed :- 31 Knots

Propulsion Power :- 110,000 SHP

Construction Cost :- US \$145,000,000

Shipbuilder :- Odense Steel Shipyard Ltd

The trade route selected for this analysis was a route that runs from Shanghai to Long Beach. This trade route is estimated to be 5800 nautical miles in length. This two port trade route was selected because it was considered to be the most viable route since it would minimize the number of ports that would have to be upgraded in order to provide the necessary husbandry services for the design vessel. Furthermore these two ports are among the largest and most modern shipping ports in the entire world. Since ports-of-call of a nuclear powered vessel are going to be required to provide services that a conventional port-of-call would not, the

assumption was made that only the largest of ports would be willing to make the required accommodations.



### **Detailed Analysis:-**

A speed versus power curve is obtained for Emma Maersk:-

$$P_{\text{eff}} = C V^3$$

$P_{\text{eff}}$  = effective shaft horsepower

$C$  = constant

$V$  = ship's speed in knots.

Despite the fact  $C$  is a function of many factors (ship's speed, ship size, hull geometry, sea state, water depth, fouling, etc.) it generally does not vary significantly over the range of operations. Therefore, it was assumed to be equal to a constant value for the purpose of this analysis.

As the above equation shows, the ship's speed and the required horse power needed to develop that speed are related to one another via a cubic relationship. there is a tremendous amount of power required to propel a ship of this size at a relatively high rate of speed. This ship needs 63,647 SHP to go at 25 knots and to go at 31 knots it would require almost double power. Also worth noting is the fact that the fuel consumption of a marine engine also follows a very similar cubic relationship.

A discussion of the benefits and drawbacks associated with producing a larger reactor to propel the ship faster. It is obvious from a cursory analysis that a faster speed would be more desirable than a slower speed. Consider a fleet of ships operating on the proposed trade route. If a shipping company had a fleet of six 10,000 TEU cargo ships operating on this route travelling at an average speed of 25 knots, then it could move 60,000 TEUs every 240 hrs (every 10 days). If the speed of the fleet were increased to 35 knots then the same amount of cargo could be moved every 171 hrs (every 7.14 days). This would translate to 11 more port visits per year for the higher speed fleet, which means that 6,60,000 more TEUs would be transported by the faster fleet each year. Or, if looked at in terms of the number of ships in the fleet, the same amount of cargo that is carried by a fleet of 6 ships travelling at an average speed of 25 knots could be carried by a fleet of only 4 ships, if those ships travelled at an average speed of 35 knots on our proposed trade route. However, as is evident from the above equation there is a penalty to be paid in terms of powering for this increase in speed. This extra power comes in the form of extra weight and space needed for larger propulsion equipment and associated systems, which in turn reduces the amount of cargo that the ship is able to ultimately carry. We can show one comparison of different engine types:-

### **Total System Power Density Comparison:-**

Vehicles like ships carry their own fuel. One of the main reasons for converting ships from coal to oil rested on the fact that oil has more energy per unit weight. Therefore, we need to compare the power density of various types of engines including stored fuel. When fuel for a ten day voyage is taken into consideration, nuclear plants can have a decided advantage over combustion plants. This advantage allows a greater portion of the ship to be dedicated to carrying revenue generating cargo.

### **Power density for various engines with 10 day fuel supplies:-**

Engine Type	Specific weight
Nuclear gas turbine	15 kg/kw
Nuclear steam plant	54 kg/kw
Diesel engine (.2 kg/kw-hr)	58 kg/kw
Combustion gas turbine (.24 kg/kw-hr)	60 kg/kw

### **Choosing The Type Of Reactor:-**

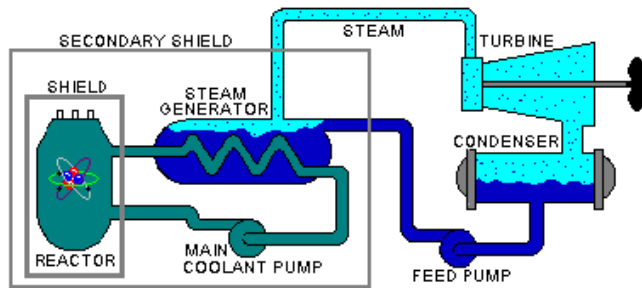
We will choose the type of reactor to be used in our nuclear propelled Emma Maersk with some of these basic considerations:-

1. The design must consider the possible adverse effects of flooding.
2. The design must consider water tight integrity between compartments.
3. The design must take into account the constraints of being on a ship; namely volume and area constraints.

4. The design must consider the weight of the reactor and the placement on the ship, as this will essentially be a point load which could potentially affect the bending moment of the ship.

The Pressurized Water Reactor (PWR) has the advantage of being the reactor of choice for all but one U.S. Navy nuclear powered vessel, and also being the reactor of choice for all previously attempted commercial nuclear powered vessels. The PWR would meet all the above requirements and has proven technically feasible in all maritime endeavors thus far.

The PWR Reactor



The total operating lifetime of the reactor core was to be either 5 years or 10 years. This decision was made to ensure that a reactor refueling could be performed in conjunction with the required dry docking inspection in order to minimize the down time of the ship.

### **Licensing:-**

The licensing of the nuclear reactor presents a problem. This is because there are currently no worldwide commercial cargo ships that are nuclear powered, so the question arises as to who will license reactor and who will provide the oversight.

The United States Navy has an organization known as Naval Reactors that has comprehensive responsibility for the design and safe operation of all the nuclear reactors that are on naval vessels. Nuclear Reactors also oversees the training of all the training of all the nuclear operators in the navy. Naval Reactors falls under the United States Department Of Energy and is the soul entity that licenses a naval vessel to operate its nuclear reactor. If nuclear powered commercial shipping is to become a reality, an organization such as this will need to be established for the commercial shipping world. This organization could be another department within the NRC itself, or could be another separate organization altogether under the department of energy.

Unlike for the case of reactor licensing, classification by any one of the major classification societies of the world is generally sufficient for a merchant vessel to go anywhere it wants to go in the world.

### **Economics:-**

If we do a study on our Example Nuclear Container Ship, the economics of implementing the nuclear reactor can be analysed:-

**Capital costs:-**

150000KW (200000 HP)

1. Assumed nuclear @ \$2500/KW
2. Assymed diesel @ \$800/KW
3. Assumed plant life 40 years
4. Assumed interest rate 10%

	<b>Capital costs:-</b>	
	Nuclear	Conventional
Plant cost	\$375,000,000	\$120,000,000
Annual plant cost	\$38,360,000	\$10,230,000
Difference	+ \$28,140,000	

	<b>Operating costs:-</b>	
	Nuclear	Conventional
Security	\$3,000,000	
Insurance	\$10,000,000	
Personal	\$1,200,000	
M&R		\$2,000,000
Reactor Disposal	\$2,000,000	
Difference	+ \$14,200,000	

	<b>Fuel costs:-</b>	
	Nuclear	Conventional
Fuel	\$0.005/KW-Hr	\$500/Mt
SFC	-	165 KG/KW-Hr
Operating Hours	9000	9000
Annual fuel costs	\$6,750,000	\$89,100,000
Difference	-\$82,350,000	-

<b>Summary:-</b>		
	Nuclear	Conventional
Capital	+\$28,140,000	
Operating	+\$14,200,000	
Fuel		+\$ 82,350,000
Total	+\$ 42,340,000	+\$ 82,350,000
Difference		+\$ 40,000,000/Yr

### **Conclusion:-**

Nuclear power is one of very few options for emission free operation of ships. Concerns regarding climate change, greater focus on emissions reduction (CO<sub>2</sub>, NO<sub>x</sub>, SO<sub>x</sub>), increased energy demands, and potential supply security problems, could increase the attractiveness of nuclear power.

The benefit of nuclear powered shipping, however, do not come without risks. Bringing nuclear shipping to a commercially viable and politically acceptable level will demand appropriate risk mitigation.

United Codes, standards, or practices for safe and efficient operations would be established before implementation of nuclear powered ships. Large vessels, fixed routes, and possibility of ship owners owning ports might attract more investors.

Several nuclear shipping concepts seem technically feasible, e.g. Ultra Large Ore Carriers, Ultra Large container Carriers, Ice breakers, etc. but not limited to.

Only ship owners with strong financial background will be able to afford the high investment. A country with an existing nuclear infrastructure is a preferred choice for building a nuclear powered ship. The economic incentive for choosing to build a nuclear powered ship is the reduction in fuel costs. This comes at the expense of an investment cost of 2.25 times that of a conventionally powered ship.

A nuclear powered container ship appears to be more profitable than a conventionally powered ship at today's fuel price. The total lifecycle cost is estimated to be 16% less for the nuclear ship.

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