

TRANSTECH '15

NUCLEAR POWERED
MERCHANT SHIPS

BY

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1. ABSTRACT

With increasing attention being given to greenhouse gas emissions arising from burning fossil fuels for international air and marine transport, particularly dirty bunker fuel for the latter, and the excellent safety record of nuclear powered ships, it is quite conceivable that renewed attention will be given to marine nuclear powered ships, it is likely that there will be renewed interest in marine nuclear propulsion. Major Nation's naval submarine has been equipped with nuclear power plant & nuclear weapon. This is done for destroying their enemies. Why didn't they advise to build a nuclear powered merchant ship for the world trading without any environmental pollution such as air pollution and water pollution?

This paper deals with the nuclear propulsion, binding energy of nucleus, calculation of energy liberated during nuclear fission, what it is nuclear fission? And discussions about challenges that has to be faced during operation, defueling and disposal of ships after its service at sea. It is essential to ensure that the nuclear powered ship has to very sound in its construction and safety to operate. This paper deals with safety precaution to be taken and also shows the example of nuclear powered naval submarines and some of successful civil ships. And this is the time to start converting the heavy fuel powered ships into nuclear powered ship. Since, all the ship can't be converted at a time. Without any effect in world trade, ships have to be powered by nucleus. Since crude oil will be finished within some decades. So that, nuclear powered ships is the solution for the above problems

2. Keywords:

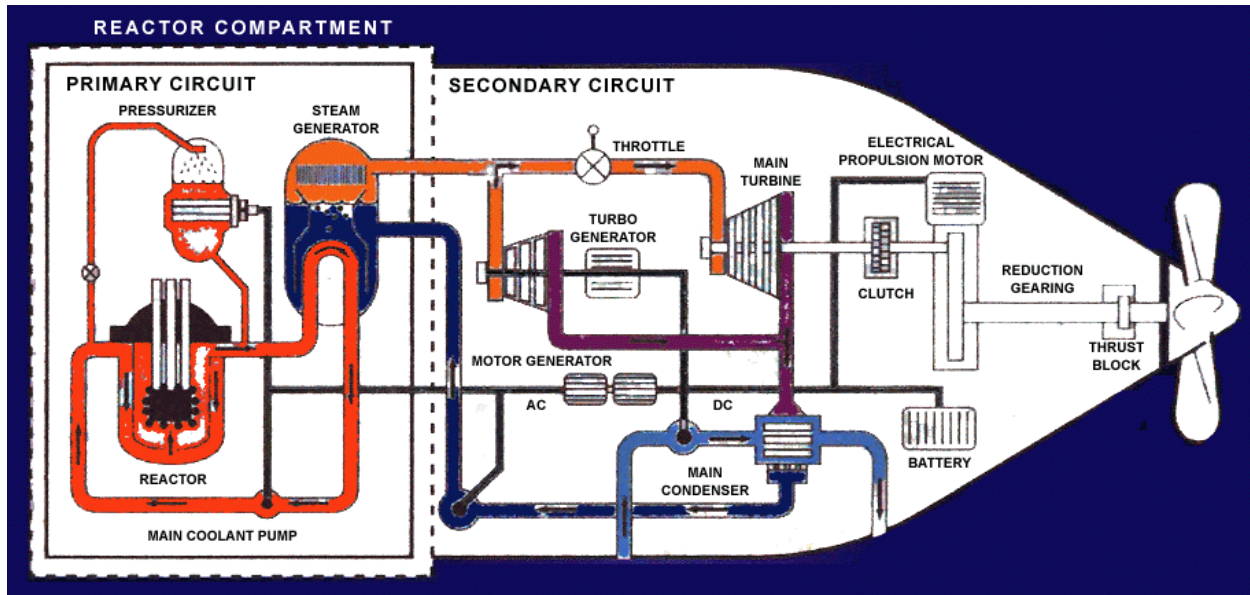
Green house emission, submarine, nuclear propulsion, de-fueling, environmental pollution

3. Introduction to Nuclear Propulsion

A nuclear-powered ship is constructed with the nuclear power plant inside a section of the ship and which is secured with in the reactor compartment. The components of the nuclear power plant include a high-strength steel reactor vessel, heat exchanger(s) (steam generator), and associated piping, pumps, and valves. Each reactor plant contains over 100 tons of lead shielding, part of which is made radioactive by contact with radioactive material or by neutron activation of impurities in the lead.

The propulsion plant of a nuclear-powered ship or submarine uses a nuclear reactor to generate heat. The heat comes from the fission of nuclear fuel contained within the reactor. Since the fission process also produces radiation, shields are placed around the reactor so that the crew is protected.

The nuclear propulsion plant uses a pressurized water reactor design which has two basic systems - a primary system and a secondary system. The primary system circulates ordinary water and consists of the reactor, piping loops, pumps and steam generators. The heat produced in the reactor is transferred to the water under high pressure so it does not boil. This water is pumped through the steam generators and back into the reactor for re-heating.



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In the steam generators, the heat from the water in the primary system is transferred to the secondary system to create steam. The secondary system is isolated from the primary system so that the water in the two systems does not intermix.

In the secondary system, the steam flows from the steam generators to drive the turbine generators, which supply the ship with electricity, and to the main propulsion turbines, which drive the propeller. After passing through the turbines, the steam is condensed into water which is fed back to the steam generators by the feed pumps. Thus, both the primary and secondary systems are closed systems where water is re circulated and renewed.

4. Nuclear reactor

The power reactors can be classified into boiling water reactor, pressurized water reactor, pressurized heavy water reactor and fast breeder reactor depending upon the choice of the moderator and the coolant used.

4.1 Fissile material or fuel

The fissile material or nuclear fuel generally used is ${}_{92}\text{U}^{235}$. But this exists only in a small amount (0.7%) in natural uranium. Natural uranium is enriched with more number of ${}_{92}\text{U}^{235}$ (2 – 4%) and this low enriched uranium is used as fuel in some reactors. Other than U^{235} , the fissile isotopes U^{233} and Pu^{239} are also used as fuel in some of the reactors.

Kamini [Kalpakkam minireactor] is the only operating reactor in the world which uses ^{235}U as fuel. In this reactor, the fuel is an alloy of uranium and aluminium and is in the form of plates.

4.2 Moderator

The function of a moderator is to slow down fast neutrons produced in the fission process having an average energy of about 2 MeV to thermal neutrons with an average energy of about 0.025 eV , which are in thermal equilibrium with the moderator. Ordinary water and heavy water are the commonly used moderators. A good moderator slows down neutrons by elastic collisions and it does not remove them by absorption. The moderator is present in the space between the fuel rods in a channel. Graphite is also used as a moderator in some countries.

4.3 Neutron source

A source of neutron is required to initiate the fission chain reaction for the first time. A mixture of beryllium with plutonium or polonium is commonly used as a source of neutron.

4.4 Control rods

The control rods are used to control the chain reaction. They are very good absorbers of neutrons. The commonly used control rods are made up of elements like boron or cadmium. The control rods are inserted into the core and they pass through the space in between the fuel tubes and through the moderator. By pushing them in or pulling out, the reaction rate can be controlled.

4.5 The cooling system

The cooling system removes the heat generated in the reactor core. Ordinary water, heavy water and liquid sodium are the commonly used coolants. A good coolant must possess large specific heat capacity and high boiling point. The coolant passes through the tubes containing the fuel bundle and carries the heat from the fuel rods to the steam generator through heat exchanger. The steam runs the turbines to produce electricity in power reactors.

The coolant and the moderator are the same in the PHWR and PWR. In fast breeder reactors, liquid sodium is used as the coolant. A high temperature is produced in the reactor core of the fast breeder reactors. Being a metal substance, liquid sodium is a very good conductor of heat and it remains in the liquid state for a very high temperature as its boiling point is about 1000°C .

4.6 Neutron reflectors

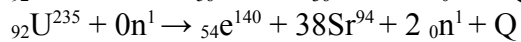
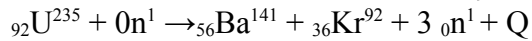
Neutron reflectors prevent the leakage of neutrons to a large extent, by reflecting them back. In pressurized heavy water reactors the moderator itself acts as the reflector. In the fast breeder reactors, the reactor core is surrounded by depleted uranium (uranium which contains less than 0.7% of ^{235}U or thorium (^{232}Th) which acts as neutron reflector. Neutrons escaping from the reactor core convert these materials into Pu^{239} or U^{233} respectively.

4.7 Shielding

As a protection against the harmful radiations, the reactor is surrounded by a concrete wall of thickness about 2 to 2.5 m.

5. What it is nuclear fission?

The process of breaking up of the nucleus of a heavier atom into two fragments with the release of large amount of energy is called nuclear fission. The fission is accompanied of the release of neutrons. The fission reactions with ${}_{92}\text{U}^{235}$ are represented as



6. Binding energy

When the protons and neutrons combine to form a nucleus, the mass that disappears (mass defect, Δm) is converted into an equivalent amount of energy (Δmc^2). This energy is called the binding energy of the nucleus.

$$\therefore \text{Binding energy} = [Zm_p + Nm_n - m] c^2 = \Delta m c^2$$

If the binding energy is large, the nucleus is stable and vice versa.

7. Energy released in fission

Let us calculate the amount of energy released during the fission of ${}_{92}\text{U}^{235}$ with a neutron.

The fission reaction is ${}_{92}\text{U}^{235} + {}_0\text{n}^1 \rightarrow {}_{56}\text{Ba}^{141} + {}_{36}\text{Kr}^{92} + 3{}_0\text{n}^1 + Q$

Mass of ${}_{92}\text{U}^{235} = 235.045733$ amu

Mass of ${}_0\text{n}^1 = 1.008665$ amu

Total mass of the reactant = 236.054398 amu

Mass of ${}_{56}\text{Ba}^{141} = 140.9177$ amu

Mass of ${}_{36}\text{Kr}^{92} = 91.8854$ amu

Mass of 3 neutrons = 3.025995 amu

(3×1.008665)

Total mass of the products = 235.829095 amu

\therefore Mass defect = 236.054398 – 235.829095 = 0.225303 amu

As, 1 amu = 931 MeV, energy released in a fission =

$0.225303 \times 931 = 200$ MeV

8. Challenges in nuclear propulsion

The internals of a floating reactor remain inaccessible for inspection or replacement throughout a long core life -- unlike a typical commercial nuclear reactor, which is opened for refueling roughly every eighteen months.

Floating reactors has to be withstanding ship's pitching and rolling and rapidly-changing demands for power, possibly under maneuvering and in heavy seas. These conditions -- combined with the harsh environment within a reactor plant, which subjects components and materials to the long-term effects of irradiation, corrosion, high temperature and pressure

9. Defueling

The defueling process removes the nuclear fuel from the reactor pressure vessel and consequently removes most of the radioactivity from the reactor plant. A disposal method for the defueled reactor compartments is needed when the ships are no longer needed. So that the ship can be: (1) placed in protective storage for an extended period; or (2) prepared for permanent disposal or recycling. The preferred alternative is land burial of the entire defueled reactor compartment.

A ship can be placed in floating protective storage for an indefinite period. Nuclear-powered ships can also be placed into storage for a long time without risk to the environment. The ship can be maintained in floating storage. About every 15 years each ship would have to be taken out of the water for an inspection and repainting of the hull to assure continued safe waterborne storage. However, this protective storage does not provide a permanent solution for disposal of the reactor compartments from these nuclear-powered ships. Thus, this alternative does not provide permanent disposal.

About 99.9% of radioactive products could be removed while defueling. Since 0.1% of radioactive products are deposited over the piping due to circulation of coolant and could not be removed.

Before a ship is taken out of service, defueling is done. Again the ship can be refueled and returned to service. Otherwise, reactor compartment can be disposed into lands by enclosing deep dig. Prior to disposal, the reactor pressure vessel, radioactive piping systems and the reactor compartment disposed package would be sealed. As time goes on radioactive atoms change into nonradioactive atoms.

10. First nuclear powered naval vessel

Work on nuclear marine propulsion started in the 1940s, and the first test reactor started up in USA in 1953. The first nuclear-powered submarine, *USS Nautilus*, put to sea in 1955.

11. Nuclear powered Naval Fleets

At the end of the Cold War, in 1989, there were over 400 nuclear-powered submarines operational or being built. At least 300 of these submarines have now been scrapped and some on order cancelled, due to weapons reduction programs*. Russia and USA had over one hundred each in service, with UK and France less than twenty each and China six. The total today is understood to be about 140, including new ones commissioned. Most or all are fuelled by high-enriched uranium (HEU).

12. Nuclear powered Indian naval fleets

India launched its first nuclear submarine in 2009, the 6000 dwt *Arihant* SSBN, with a single 85 MW PWR fuelled by HEU driving a 70 MW steam turbine. It is reported to have cost US\$ 2.9 billion. The *INS Aridaman* SSBN is under construction at the Ship Building Centre in Visakhapatnam, and due to be launched in 2015. Another SSBN and six nuclear SSNs are planned. India is also leasing an almost-new 7900 dwt (12,770 tonne submerged) Russian *Akula-II* class nuclear attack submarine for ten years from 2010, at a cost of US\$ 650 million.

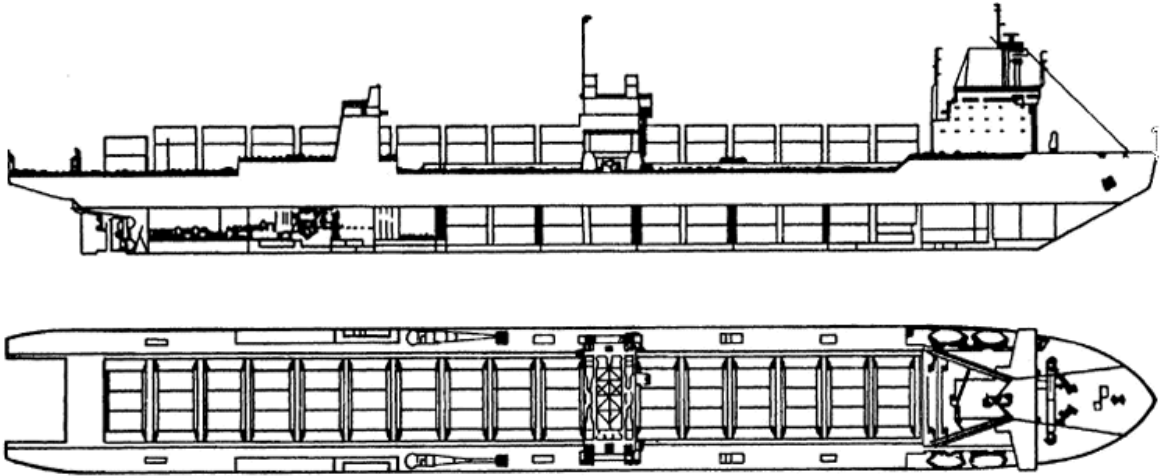
13. Nuclear powered Merchant ship

The German-built *Otto Hahn*, a cargo ship and research facility, sailed some 650,000 nautical miles (1,200,000 km) on 126 voyages over 10 years without any technical problems. However, it proved too expensive to operate and was converted to diesel.



In 1988 the *NS Sevmorput* was commissioned in Russia, mainly to serve northern Siberian ports. It is a 61,900 tonne 260 m long LASH-carrier (taking lighters to ports with shallow water) and container ship with ice-breaking bow capable of breaking 1.5 metres of ice. It is powered by a KLT-40 reactor similar to the OK-900As used in larger icebreakers, but with only 135 MWt power delivering 32.5 MW to the propeller. It needed refueling only once to 2003. The reactor was to be decommissioned about 2014, but Rosatom has approved overhauling it so that the ship is returned to service in 2016. As of 2012, it is the only nuclear-powered merchant ship in service.

Image of Construction detail of sevmorput is given below:



14. Protection against radiation

- (1) Radioactive materials are kept in thick-walled lead container.
- (2) Lead aprons and lead gloves are used while working in hazardous area.
- (3) All radioactive samples are handled by a remote control process.
- (4) A small micro-film badge is always worn by the person and it is checked periodically for the safety limit of radiation.

15. The biological effects of nuclear radiation

- (i) Short term recoverable effects
- (ii) Long term irrecoverable effects and
- (iii) Genetic effect

16. REFERENCES:

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Tamilnadu Textbook Corporation