NUCLEAR WATER RAMJET BASED ON PLUTONIUM POWERED FAST BREEDER REACTOR WITH TWO LOOPED LIQUID METAL COOLING

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Abstract: Merchant ships are craving for a prismatic change in terms of their power derivation sources. The use of nuclear energy power and Steam jet injection will not only deter the pollution prevalent by their shared shipping space but also the decrement caused by the slow speed. This will actually break all the speed and handling barriers on the ships, be it war or merchant vessel. The current propeller used in ships has many disadvantages, like vibration, cavitation, etc. Maneuverability at low speed will increase many folds.

Apart from that the world is at a verge of oil crisis, Extreme geopolitical conditions and increasing pollution levels is an indication, that we need to switch our fuel. Complete eradication of Sox and NOx is one of the perks. Although the use of nuclear reactors to propel ships in the years since that historic day has been primarily limited to naval vessels, interest in the potential for nuclear power to drive merchant ships is currently resurgent. The high price of oil and growing pressures to reduce ship atmospheric emissions are supporting a reappraisal of the role nuclear power might play in the future.

As oil prices have skyrocketed in the decades, the cost of building a marine nuclear propulsion system has dropped dramatically, not least because of the advances in technology, and the ability to construct relatively small "appliance grade" reactors customized for the requirements of a particular ship. Reactor designers are also at pains to highlight the advances that have been made in controlling and minimizing risk and enhancing safety and reliability.

We propose a Nuclear Powered, propeller-less ship. The marine propulsion here, works on the phenomenon of steam jet injection into the water and two phase mixing.

The power source is a Fast Breeder Reactor , with a Plutonium matrix in a dodecahedron structured core. Nuclear shield has a Boron coated Zirconium, followed by Quartz glass, thick stainless-steel containment vessel, Graphite for biological shielding and lead at last for absorption. It has two loop of liquid metal, first loop being liquid Sodium, and second, the eutectic solution of Lead-Bismuth. Lead-Bismuth Solution is then, passed through a Honeycomb type heat-exchanger, with other side being sea-water, impelled through a pump, this causes the sea water to vaporize into saturated vapor.

The pressure gradient across the tube(nozzle), accelerates steam to supersonic speeds thus transferring the internal energy to kinetic energy. Direct contact heat transfer takes place between water and steam. Steam undergoes a condensation process which ultimately results in a localized compressive shock within the flow. The condensation shock results in large pressure differences which subsequently lead to significant fluid motion.

The result of this mixing is a fairly high velocity and temperature 'fluid mixture' containing regions of both sub-cooled fluid and super-saturated steam. This fluid mixture now has the increased mass and kinetic energy, required to propel the ship.

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ADVANTAGES OF NUCLEAR PROPULSION

- Long periods between refueling operations and considerable endurance range for vessel after each refueling. [capabilities like dry-dock to dry-dock refueling operation is easily possible].
- Huge quantities of fuel need not be transported with resultant weight savings and space needed for fuel, besides a reduction in manpower required for refueling operation.
- As nuclear power in not dependent on air for combustion, it is very useful choice for sub marine propulsion. For surface ship there is not exhaust to give the ship a neat Signature and no pollution to atmosphere by exhaust emissions.
- There are no changes in ship draft and trim as the fuel is consumed.
- Nuclear plant is very simple to control, it responds Instantly to load demand changes and can supply quantities of high-pressure steam.
- Technology such nuclear gas turbine can cause to increase the Dynamic advantages combining those of nuclear power plant and Gas turbine and getting steam out of the equation.

SPEED

An example calculation might help explain the characteristics of nuclear propulsion that allow it to claim a speed advantage over oil burning ships. If a ship needs 26,000 shaft horsepower to travel at 17 knots, it will burn about 1700 gallons (6.4 tons) of bunker fuel every hour. If the same ship wished to increase speed to 25 knots to make a delivery schedule, the fuel rate would increase to 8500 gallons (32 tons) per hour while the power needs would increase to 130,000 SHP. It is obvious why fast ships are not generally considered to be an economical way to transport bulk cargo.

Even if oil is cheap, the space required for storage for a long trade route becomes a major concern. A ship like the above carrying goods from New York to Cape Town, South Africa would need at least 2.3 million gallons of fuel (6900 tons) to make the trip at 25 knots versus 673,000 gallons (2019 tons) at 17 knots. Even though the trip takes five days longer, space and fuel costs favor the slower journey.

With nuclear ships, fuel expenditures are minor, both in terms of weight and cost. At current nuclear fuel prices an SHP hour produced by fissioning slightly enriched uranium fuel costs less than one sixth as much as an SHP hour produced by burning residual oil. The advantage is even more dramatic when compared to distillate fuels. There is virtually no change in weight on a nuclear-powered ship because of fuel consumption.

There are obvious advantages to increased speed if fuel consumption is less constraining. More cargo can be moved with the same number of ships. Cargo will spend less time at sea and more time where it is needed. Shippers will pay higher rates for certain types of cargo since they will save on financial carrying costs. Since a faster ship requires the same crew size as a slow one, productivity can increase be improved without painful layoffs.

RELIABILITY

Nuclear ships have demonstrated a high degree of reliability. They have operated for decades in some of the world's harshest climates including the Persian Gulf and the Arctic Ocean. They are not subject to clogged fuel filters, burst fuel lines, loss of compressed starting air, contaminated fuel from substandard suppliers, bent rods, failed gaskets, or a whole host of other problems common to combustion engines. Even single reactor plant submarines comfortably operate under the Arctic ice cap where a loss of propulsion power can be deadly. The engines rarely fail. Since a substantial portion of the marine accidents can be blamed on propulsion casualties, this characteristic is an important advantage for nuclear power.

POWER DENSITY COMPARISION

Conventional wisdom holds that the weight of shielding needed for nuclear powered ships is more than the weight saved by the lowered fuel consumption. Savannah's propulsion plant

Power density of typical engine types

Engine type	Specific weight
combustion gas turbine	2.9 kg/kw
medium speed diesel	10 kg/kw
nuclear gas turbine (including shielding)	15 kg/kw
nuclear steam plant (including shielding)	54 kg/kw

weighed about 2500 tons including the shielding. Her specific power ratio was 238 lbs./hp (151 kg/kw), which is obviously not very competitive with today's medium speed diesels or gas turbines. However, Savannah's propulsion plant weight included enough fuel for 340,000 miles of operation. In contrast, a diesel engine system with a specific weight of 36 lbs./SHP (23 kg/kw) and a specific fuel consumption of .3 lbs./hp-hr. (.2 kg/kw-hr) would match Savannah's characteristics if its required voyage lasted 28 days (13,000 miles at 20 knots), ignoring the weight of tanks, and piping and reserve fuel requirements.

Actually, the comparison between a modern diesel and a 1950s first generation nuclear plant with a low-pressure saturated steam plant does not provide a realistic picture of what a nuclear plant can achieve. The below table, which includes ducts and foundations, provides better information.

SPECIFIC VOLUME COMPARISON

Many of today's ships are more limited by space than by displacement. Nuclear propulsion plants, with high density materials making up a large portion of their weight, have an advantage over fossil fueled ships. A nuclear gas turbine plant would require approximately 60% of the volume of an equivalent combustion gas turbine for a nominal 10-day voyage; the advantage increases for longer ranges.

Container ships, like aircraft carriers, need as much free deck space as possible. This requirement is one thing that has inhibited the use of marine gas turbines, which require a high air flow and subsequently require large intakes and exhausts. Nuclear gas turbines, however, have no need for intakes and exhausts. The space saved on deck can increase operating efficiencies and revenues for the life of the ship.

THE ENVIRONMENT

In most ports, it is illegal to discharge oil contaminated water. This has led to the development of segregated ballasting systems to ensure that compensating water is not contaminated. There are also limits associated with biological hazards that prevent the discharge of ballast water taken in at a different port. Nuclear ships have no need to compensate for changes in fuel weight during a voyage so they can have simpler ballasting systems.

Governments have implemented air emission limits in certain busy ports that require costly modifications to existing propulsion systems.

Simple, but somewhat costly, solutions include separate bunkers with low sulfur (but more expensive) oil, and ship speed (power) limits when within certain boundaries. There is increasing pressure for the installation precipitators, selective catalytic reformers and scrubbers. Aside from the expense, these technologies can be difficult to adapt to ships because of space limitations. Nuclear ships do not emit any exhaust gases, a fact that is clearly demonstrated by the success of nuclear powered submarines.

LIQUID METAL COOLED FAST BREEDER REACTOR LMFBR

Nuclear reactors are basically of two types, **Thermo-nuclear** and **fast breeder**.
Thermo nuclear reactors are usually used for power generation on land, while fast breeders are known for their high energy density, they are more compact and produces enormous amount of energy through fast moving neutrons.
Moreover, a breeder reactor produces more fissionable material that can used to fuel other plants.

Neutrons produced by fission have high energies and move extremely quickly. These fast neutrons do not cause fission as efficiently as slower-moving ones so the process of moderation, which utilizes a liquid or gas moderator such as water or helium is used to cool the neutrons to optimum energies and thereby slow them down. These slower neutrons are brought to the same temperature as the surrounding neutrons and are called "thermal neutrons".
In contrast to most normal nuclear reactors, however, a fast reactor uses a coolant that is not an efficient moderator, such as liquid sodium, so its neutrons remain high-energy. Although these fast neutrons are not as good at causing fission, an isotope of uranium (U238) captures them and consequently becomes plutonium (Pu239) which can be reprocessed and used as more reactor fuel or in the production of nuclear weapons. Reactors can be designed to produce more fuel than they consume, through the maximization of plutonium production. These reactors are called breeder reactors.

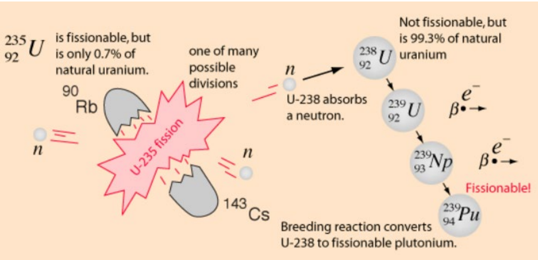
Breeder reactors are possible because of the proportion of uranium isotopes that exist in nature. Natural uranium consists primarily of U238, which does not fission readily, and U235, which does. Natural uranium, only 0.72 percent of which is U235, cannot sustain a chain reaction and therefore cannot be used in a nuclear reactor. Commercial nuclear reactors normally use uranium fuel that has had its U235 content enriched to somewhere between 3 and 8 percent by weight. Although the U235 does most of the fissioning, U238 makes up for 90 percent of the atoms in the fuel as they are potential neutron capture targets and future plutonium atoms.

Pu239, which is created when U238 forms U239 (after capturing a neutron) and undergoes two beta decays, happens to be even better at fissioning than U235. Pu239 is formed in every reactor and also fissions as the reactor operates. Such a plutonium fission provides the nuclear reactor with a significant amount of energy. But because this plutonium fissions, it reduces the amount that is left in the fuel and thus, to maximize plutonium production, a reactor must create as much plutonium as possible while minimizing the amount that splits.
This is why many breeder reactors are also fast reactors. Fast neutrons are ideal for plutonium production because they are easily absorbed by U238 to create Pu239, and they cause less fission than thermal neutrons. Some fast breeder reactors can generate up to 30 percent more fuel than they use. Creating extra fuel in nuclear reactors, however, is not without its concerns, the first one being that the plutonium

produced can be removed and exploited in the making of nuclear weapons. Another worry is that radioactive waste is created and the risk of potentially high radiation exposures increases, during the extraction of plutonium for the purpose of reprocessing.

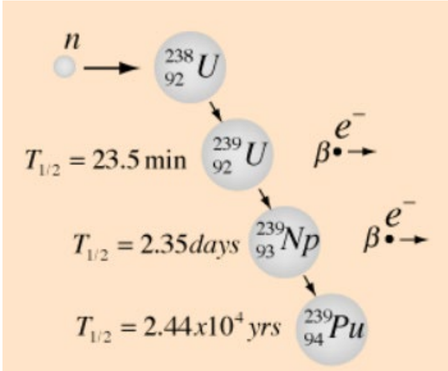
REACTOR PHYSICS

Under appropriate operating conditions, the

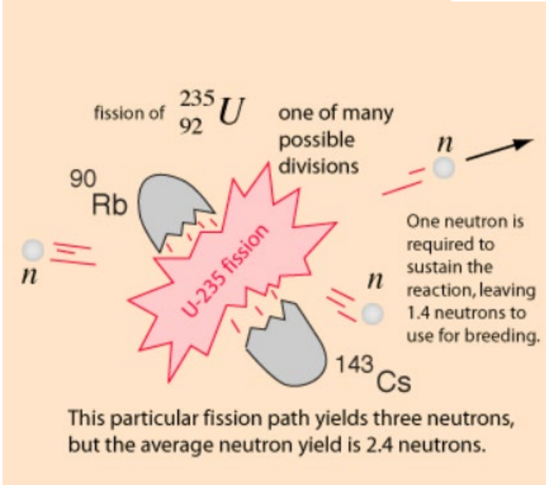


neutrons given off by fission reactions can "breed" more fuel from otherwise non-fissionable isotopes. The most common breeding reaction is that of plutonium-239 from non-fissionable uranium-238. The term "fast breeder" refers to the types of configurations which can actually produce more fissionable fuel than they use, such as the LMFBR. This scenario is possible because the non-fissionable uranium-238 is 140 times more abundant than the fissionable U-235 and can be efficiently converted into Pu-239 by the neutrons from a fission chain reaction.

Fissionable plutonium-239 can be produced from non-fissionable uranium-238 by the



reaction shown. The



bombardment of uranium-238 with neutrons triggers two successive beta decays with the production of plutonium. The amount of plutonium produced depends on the breeding ratio.

In the breeding of plutonium fuel in breeder reactors, an important concept is the breeding ratio, the amount of fissile plutonium-239 produced compared to the amount of fissionable fuel (like U-235) used to produced it. In the liquid-metal, fast-breeder reactor (LMFBR), the target breeding ratio is 1.4 but the results achieved have been about 1.2. This is based on 2.4 neutrons produced per U-235 fission, with one neutron used to sustain the reaction.

The time required for a breeder reactor to produce enough material to fuel a second reactor is called its doubling time, and present design plans target about ten years as a doubling time. A reactor could use the heat of the reaction to produce energy for 10 years, and at the end of that time have enough fuel to fuel another reactor for 10 years.

REACTOR DESIGN SAFETY FEATURES:-

Particular points especially emphasized in design and the commercial safety are: -

1) No one in the control area shall be exposed to radiation exceeding hall the allowable limit the radiation shields are designed for the following conditions less than 0.5 rem/yr in the non-controlled area, less than 5 rems/ year in controlled area, where any one can enter, except for inspection for a limited time. The reutilization system is divided into two sections, one for areas where radioactive.

1. Contamination may occur and another for areas where it never occurs inside the reactor container, the reactor room and reactor auxiliary rooms, the atmosphere is kept slight lower to avoid spread of inside air

2) Any hazard due to either mishandling by an operator or malfunction of control system shall be kept to a minimum instruments monitor. The condition of the reactor and its associated plant if these indicate a potentially dangerous situations or if all control electrical supplies, fail, the rod-drive motors de-energies and the reactor shuts down automatically.

3) The diffusion of radioactively shall be prevented by installing the reactor vessel and accessory instrumentation in a steel container, which also protests the reactor plants against free flooding. At the bottom of container two sets of pressure balancing valve are provided to present the rupture of the container by external pressure in the event of sinking. The valves open at pressure difference of 2 kg/cm2 so sea water can flow into the container and will close again after the divination of pressure difference.

4) The steel container should always be safe against such as collision or stranding being located in the center of the well and protected on all sides with reinforced structure. Three reactor itself, the reactor auxiliary equipment and the reactor service area forward of the machinery space are auxiliary rooms are equipped with anti-collision structure of uniform strength around the front and back of reactor. Both sides of these rooms re equipped with anti-collision structure, which consists of six decks of thicker plates. In event of collision, the energy will be absorbed by this structure, thus not damaging the container and the installations in the reactor and it's a built-up lattice composed of stranding, this structure will protect the inner bottom plate against breakages and two protect the reactor container and other installation.

5) The two – compartment standard and strict stability criteria will be applied to prevent an eventual foundering

6) Fireproof constructions, fire detecting system and fore extinguishing systems are to be sufficiently installed throughout the ship, non-combustible materials are to be used for furnishing.

7) Dust type installations and the principal of dispersal are adopted to ensure the security of functioning of all equipment. For safe and smooth operation, it is important that all the important parts in the primary circuit duplicated so that if one of them fail other can take over the charge.

8) Emergency devices and the safety systems associated with reactor plant shall operate satisfactorily when subjected to the following: -

- Roll 60^0 – single amplitude
- Pitch 20^0 – single amplitude
- List 60^0 – Trim – 20^0
- Vertical acceleration: 1+1.3g, other ascertain – 1.0 g

This is conversion reactors converts U^{238} in to Pu^{239} and Th^{232} into U^{233}

POSITION OF REACTOR ON THE SHIP

Positioning a reactor in a ship, is a matter of high importance, as it is directly related to the ship's dynamics and safety of the crew members, passenger, marine biology and the environment. Reactors are mostly disturbed by the motion of higher amplitude. A ship if considered, the minimum amplitude of various ship motions is found to be in the rough mid-point of the ship. Moreover, as presented in a paper by J S Carlton, we can see, the same conclusion, putting it at the bow or stern will further expose it to greater chance of damage due to collision and higher amplitude of motion.

There are various methods that are employed to reduce the undue motion, that is described in a paper 'Seismic analysis of LMFBR' by RJ Gibert. The electronic and control systems used are affected by the neutron flux, and temperature that may further deviate the calibrations. A faulty control system may cause many accidents.

Hence putting the reactor at the center longitude satisfies various constraints put on it. Also, a pressurized Water Reactor PWR, is quite heavy, and to make the ship dynamically and statically stable, our prime focus should be to place the reactor as low as possible, in order to keep the center of gravity Cg low.

REACTOR DESIGN AND SHIELDING

Nuclear shield has a boron coated Zirconium, followed by quartz glass and thick stain-less steel containment. Graphite for Biological shielding and lead pool covering at last for absorption.

The proposed reactor in this paper is plutonium based in the first stage and models of the series and then thorium based in the second stage liquid metal cooled fast breeder reactor or LMFBR.

These reactors use plutonium as fuel. Plutonium undergoes fission which a high a large speed neutron strikes it these reactors don't require any moderator other elements of this reactors are similar to thermonuclear reactors Fast reactors although not in much use at the present are gaining importance as try have many advantages over thermal reactors. Fast reactors use plutonium which is produce artificially when U-238 atom absorbs a neutron this can be achieved by surrounding the core with a blankets of U-238 which is gradually converted to plutonium by bombardments with neutrons escaping from the core.
The uranium found in the earths crust is 99.3% U-238 and 0.7%U-235. Hence fast reactors enhanced the life of the fuel. For the same power output the fuel required would be less and hence the fast breeder reactors are much smaller in size than thermonuclear reactor since the size of the reactors is smaller for efficient that transfer metal coolant such as sodium is used.

MATERIAL AND THE REACTOR STRUCTURE

The essential requirements for materials are now high melting point, relation of satisfactory physical and mechanical property at high temperatures, and good corrosion resistance especially to molten sodium. Metals and alloys of particular interest are **stainless steels,**

niobium, molybdenum, tantalum and tungsten. The latter two leaving very high melting point substances, for e.g. tantalum is 3400ºC, their thermal neutron cross section is very high and they are brittle, and somewhat difficult to fabricate. Tantalum on the other hand, can be fabricated without undue difficulty and resists the action sodium up to 1200ºC, it can also contain molten plutonium-iron fuel. Austenitic stainless steel of variety 304, 304.c, 309S Nb, 31B, 316L, 347 are found suitable for reactor applications. Nickel used for manufacture of these stainless shall less than 0.0012% of Cobalt as contaminant to prevent the formation of radioactive Co-60. They should be able to resist intergranular attack, of sensitized material, stress corrosion cracking, and local attack by Na-24.

BREEDER CORE COMPOSITION

The essential parts of a nuclear reactor (thermal or fast) are following :-

1.Fuel – combination of fertile and fissile material.
1 Fertile fuel are u238 and Th232
2 Fissile Fuel –U 233, U 235 and PU 239
3.Core - contains fuel, moderator (if any)and control rods
4.Reflector – surrounds the core and reduces the neutron leakage
5.Containment vessel-prevents escape of radioactive fission products usually made of stainless steel
6.Shielding – prevents neutrons and gamma rays from escaping into the environment, thereby causing harm to the escaping stuff
7.Coolant – removes heat from the core and transfers it to the water to generate steam. In some of the reactor ,coolant passes directly to the turbine such as boiling water and gas cooled reactors
8. Control system – Made from highly neutron absorbing material such as Boron or Cadmium .These rods are inserted into the core to lower the reaction rate and withdrawn to increase the power output.
9.Emergency system – Also includes evacuation means of Personal and citizens affected in the area of the power station. Many nuclear plants are unable to operation because of lack of proper ways to evacuation of people even though technically sound otherwise and license was granted but later with drawn after completion of power plant.

1)Inner core: U-238+Pu-239
2)Outer core: U-238+Pu-239 (higher concentration)
3)Breeding blanket(U-238)
4)Reflector elements:

- The LMFBR core is composed of two parts: core and blanket
- The fission process takes place in the core volume
- Extra neutrons diffusing out from the core are absorbed in a material (depletedU-238) Surrounding the core which is called the radial blanket.
- In the vertical direction escaping neutrons are absorbed in the vertical blanket.
- This material is directly incorporated into each fuel rod above and below the fuel region .

1. THE LOOPS

There are total three loops in the whole circuit, the Inner most liquid Sodium(Na) loop, the heat of the liquid sodium is exchanged with an eutectic solution of lead- Bismuth (Pb-Bi), being the second loop. Third loop is of water to generate steam for auxiliary purposes and propulsion.

(a) SODIUM LOOP

The inner most liquid sodium loop is again, subdivided into primary and secondary loop.

The plutonium matrix or the core is submerged in the primary loop, thus making it a high temperature pool of liquid sodium, this inner vessel is surrounded by a comparatively colder pool of sodium, that offers to cool the liquid inner sodium via a circulating pump and pipes, and also to give structural rigidity to the whole body called main vessel.
The heat transfer from inner to outer pool of liquid sodium takes place by an Intermediate Heat Exchanger IHX with the aid of Electromagnetic pumps.

Functions of the Sodium Main circuit

- To cool the sub-assemblies and transport the useful heat to the other loops.
- To make sure that sufficient level of sodium is maintained in the vessel and the fuel sub-assemblies are always immersed in the sodium.
- Detection of fuel clad rupture by detection of delayed neutrons.

The circulation system is such that natural circulation sets in due course of time in case the forced circulation fails. Also, there is no manual or motorized valve, that further reduces any chance of flow interruption. Though, there is Non-return valve provided at the discharge side of each pump. This is to prevent by-passing of the sodium in case of failure on one pump.
There is also a small back flow provided through the NR valves to keep the pumps in hot condition when the pump loop is shut down.

Vertical axis centrifugal pumps will be used to pump the liquid sodium,

Inner Hot pool of sodium: 640C
Outer cold pool: 540C

(b) LEAD-BISMUTH LOOP (Pb-Bi)

Now as sodium is highly reactive to water, our prime focus is to avoid any contamination. Hence we use a secondary loop of a eutectic solution of lead-Bismuth, that cools the hot liquid sodium.
Also, lead is a natural shield that surrounds the main vessel, thus providing the shielding action.

So, by now, we have a primary hot liquid sodium pool, secondary colder liquid sodium, and second loop of Lead-Bismuth.

With an EM pump, liquid sodium from inner pool is passed through a U-tube heat exchanger, that heats up the lead-Bismuth, Pb-Bi is drawn via pump from the outermost pool and passed through the same heat exchanger.

Melting temperature	- 396.6 K
Boiling temperature	- 1943 K
Volumetric expansion coefficient	- 1.19 x 10^{-4} K^{-1}
Volume change at melting	$-\Delta V = \frac{V_l - V_s}{V_s} \cdot 100 - (0 to 1.67)\%$

Dependence of some properties on temperature

Parameter	Temperature, °C					
	130	200	300	400	500	600
Density, ρ, kg/m^3	10570	10486	10364	10242	10120	10000
Heat capacity, c_p, J/kg·K	146	146	146	146	146	146
Kinematic viscosity, 10^8, m^3/s	31.4	24.3	18.7	15.7	13.6	12.4
Prandtl number, Pr·10^2	4.45	3.18	2.24	1.72	1.37	1.15
Heat conductivity, λ, W/m·deg.	10.93	11.74	12.67	13.72	14.65	15.81
Thermal conductivity, $a \cdot 10^6$, m^2/s	7.1	7.6	8.3	9.1	9.9	10.8

© WATER LOOP?

Now the heated lead-Bismuth is divided into various branches for different utilities, Fresh water generator FWG, Boiler for steaming the turbine for electrical power generation and the main propulsion via a Honeycomb type heat exchanger, that is described later in the propulsion topic.

The steam generated through the heating forms the basis for the power plant both closed cycle power plants for electric power generation as well as the open cycle nuclear power water steam ram jet. The high specific impulse generated by the direct steam injection of the vaporized steam jet injection into the environmental surrounding sea water is the main stay of the propulsion and power plant model of the proposed paper. The water loop is used in the steam to distilled water generator and the high-pressure steam generator for the steam turbine for the alternators and sea water injection pump (multi-stage axial pump) .

ABOUT THE SUB-ASSEMBLIES AND AUXILIARIES

(a) PIPING SYSTEMS AND REQUIREMENTS

The sodium pipelines operate at a high temperature of around 520C, and at low pressure of around 4 bar maximum. There are expansion loops and adjustable spring supports provided to take up the thermal expansions. And as all the pipes are double enveloped, the differential thermal expansion between the pipes are taken up by the compensating bellows.
The complete piping circuit in enclosed in a shielded shell, so that it remains inaccessible during operation, so that in case of sodium leak, nitrogen can be injected and the radioactive area can be ventilated.

Now as sodium is solid at the room temperature, to keep it in molten state in absence of reactor heat, the piping is to be maintained at temperature higher than 120C (melting point of sodium is 97.8C). To maintain this temperature, hot nitrogen is circulated through the double envelope, there is also a stand-by electric heating system in case of failure of the former. It will be wounded over the Double envelope.

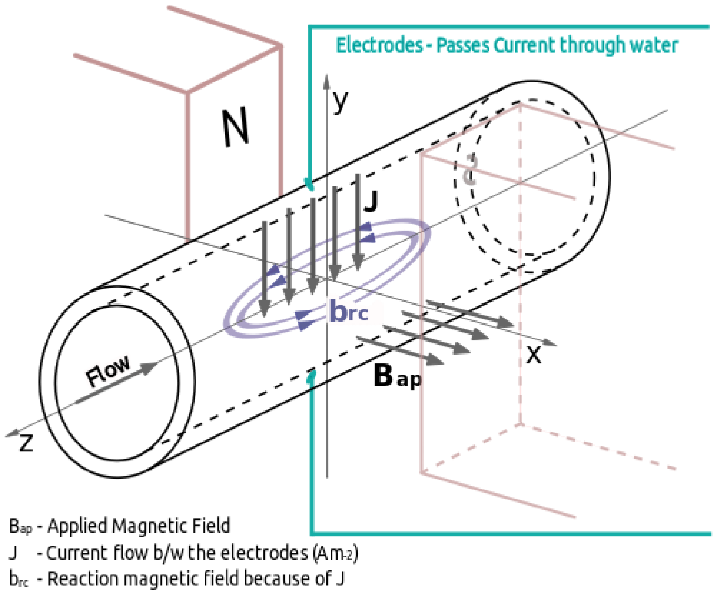
Sodium is corrosive to most of the metal, especially when its high temperature and in presence of O2 and water, hence stain-less steel is good to withstand such conditions and will resist corrosion to greater extent.

Cr/Al thermocouples are used to measure accurate temperatures, and spark plug type sodium leak detectors will also be used in the pipes.

(b) PUMPS-SODIUM PUMP

It will pump sodium from the reactor core. It is a vertical shaft centrifugal pump, placed in a fixed shell having free Sodium level. Labyrinth seals are used to prevent leakages in the suction and discharge side. Also, Non-return valve are fitted on the discharge side of the Pump, with an allowance of slight back flow. Pump speed will be controlled by a variable speed, ward- Leonard speed control system.

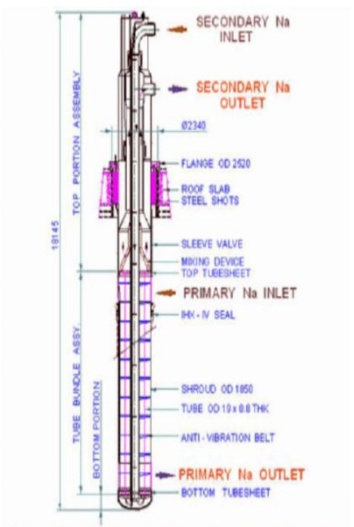
© ELECTROMAGNETIC PUMPS



2. HEAT EXCHANGERS

There are three types of heat exchangers used in the plant: -

1. Simple u-tube heat exchanger for the desalination and fresh/distilled water generation (not described due to space constraints.)
2. IHX- intermediate heat exchangers for the steam generation for the steam turbines.
3. Direct contact honey comb type propulsion heat exchanger.



INTERMEDIATE HEAT EXCHANGER (IHX)

Total thermal power of reactor	1250 MW (t)
Thermal capacity of each IHX	315 MW (t)
Primary sodium inlet flow	1650 kg/s
Primary sodium inlet temperature	544 °C
Primary sodium outlet temperature	394 °C
ΔT between primary sodium inlet and outlet	150 °C
Secondary sodium inlet flow	1450 kg/s
Secondary sodium inlet temperature	355 °C
Secondary sodium outlet temperature	525 °C
ΔT between secondary sodium inlet and outlet	170 °C
Inlet and outlet windows height	900mm
Heat exchanging tubes OD and thickness	19 and 0.8 mm
Total number of tubes	3600
Radial pitch of the rows	25mm
Circumferential pitch	26.2 mm
Heat transfer length	7.5 m
Heat Transfer Area [Based on tube OD]	1612m²
Shell diameter (Cylindrical IHX)	1850 mm/5thk
Down Comer Outer/Inner diameter	580/547mm
Number of tube rows (Cylindrical IHX)	25

An electromagnetic pump is used to pump liquid metals, with the help of a magnetic field, using electromagnetism. The angle between the magnetic field and the flow of liquid is set to 90 degrees, and a current is passed through it, that causes the electromagnetic force to move the liquid metal.

Here an EM pump is used for sodium in the overflow tank and for pumping and circulating Lead-Bismuth.

For other purposes, like in FWG and Propulsion system, normal centrifugal pumps will be used that is currently in use on board.

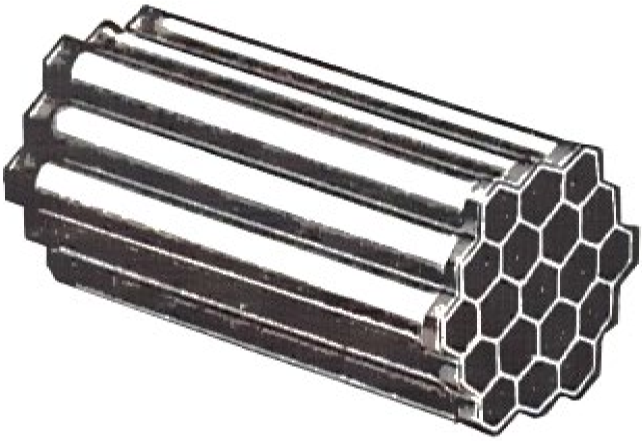
(c) IHX- INTERMEDIATE HEAT EXCHANGERS

They are basically used to transfer heat from inner heated sodium to the outer cold pool of sodium.

The pool is divided into hot and cold, by an inner vessel. The inner shell consists of two cylindrical shells of different diameters that is joined together by a conical shell (Redan). The hot sodium emerging from the core mixes and penetrates the IHX through an inlet window and travels through the inner tube or passage, While the secondary sodium circuit, passes through sides of the tube. That cools the inner shell, containing the hot primary sodium.

(d) HONEYCOMB HEAT EXCHANGERS

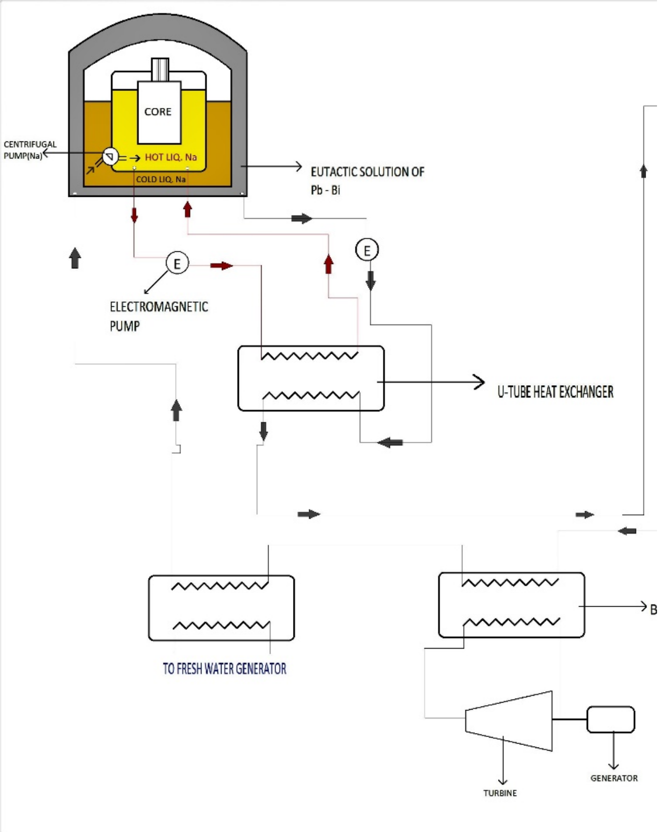
FOR PROPULSION.



This is resiliently mounted heat exchanger which is the heart of the propulsion project. This is ultra-sonically energized high frequency vibrating heat exchanger which has the following characteristics.

1. Due to ultrasonic vibration the heat exchanger is self-cleaning due to imposed cavitation action due to high frequency vibration and water near the boundary layer. It will automatically remove the excessive salt deposition from the vaporizing sea water (32000 ppm)
2. Intimate contact between the sea water and the lead bismuth heated loop. Honey comb structure results in the maximum intimate contact between the heat exchanging medium that is the lead bismuth from the secondary loop and the seawater injected into the heat exchanger by the multistage axial flow sea water pump of high capacity.
3. The heat exchanger is a single pass heat exchanger for incoming water and hence high flow rate which is non-chockable and phase change and heating happens in the heat exchanger as the media passes through the honey comb in a single pass and phase boundaries can be established linearly based on flow rate and the heat and mass transfer rates.

Simple Line diagram of the plant



PROPULSION NOZZLES

A nozzle (from nose, meaning 'small spout') is a tube of varying cross-sectional area (usually axisymmetric) aiming at increasing the speed of an outflow, and controlling its direction and shape. Nozzle flow always generates forces associated to the change in flow momentum, as we can feel by handholding a hose and opening the tap. In the simplest case of a rocket nozzle, relative motion is created by ejecting mass from a chamber backwards through the nozzle, with the reaction forces acting mainly on the opposite chamber wall, with a small contribution from nozzle walls. As important as the propeller is to shaft-engine propulsions, so it is the nozzle to jet propulsion, since it is in the nozzle that thermal energy (or any other kind of high-pressure energy source) transforms into kinetic energy of the exhaust, and its associated linear momentum producing thrust. The flow in a nozzle is very rapid (and thus adiabatic to a first approximation), and with very little frictional loses (because the flow is nearly one-dimensional, with a favourable pressure gradient except if shock waves form, and nozzles are relatively short), so that the isentropic model all along the nozzle is good enough for preliminary design. The nozzle is said to begin where the chamber diameter begins to decrease (by the way, we assume the nozzle is axisymmetric, i.e. with circular cross-sections, in spite that rectangular cross-sections, said two-dimensional nozzles, are sometimes used, particularly for their ease of direction ability). The meridian nozzle shape is irrelevant with the 1D isentropic model; the flow is only dependent on cross-section area ratios.

Converging nozzles are used to accelerate the fluid in subsonic gas streams (and in liquid jets), since at low speeds density do not vary too much, and can be approximated by vA=const. Liquid jets and low speed gas flows can be studied with classical Bernoulli equation (until cavitation effects appear in liquid flows), but high-speed gas dynamics is dominated by compressibility effects in the liquid. By the way, we do not considered here multiphase flow in nozzles. But when the flow is supersonic at some stage (even just at the exit), $p_e \neq p_0$, and a more detailed analysis is required.

$$\dot{m} = \rho v A = \text{const}$$

Before developing it, let summarise the results:

-

a. A converging nozzle can only become supersonic at the exit stage; the speed increases monotonically along the nozzle. If a converging nozzle is fed from a constant pressure constant temperature chamber, the flow rate grows as the discharge pressure is being reduced, until the flow becomes sonic (choked) and the flow rate no longer changes with further decreasing in discharge-pressure (a set of expansion waves adjust the exit pressure to this lower discharge pressure).

b. A converging-diverging nozzle ('condi' nozzle, or CD-nozzle), is the only one to get supersonic flows with M>1 (when chocked). It was developed by Swedish inventor Gustaf de Laval in 1888 for use on a steam turbine. Supersonic flow in CD-nozzles presents a rich behaviour, with shock waves and expansion waves usually taking place inside and/or outside. Several nozzle geometries have been used in propulsion systems.

c. The classical quasi-one-dimensional Laval nozzle, which has a slender geometry, with a rapidly converging short entrance, a rounded throat, and a long conical exhaust of some 15° half-cone angle (the loss of thrust due to jet divergence is about 1.7%).

d. Bell-shape nozzles (or parabolic nozzles), which are as efficiency as the simplest conical nozzle, but shorter and lighter, though more expensive to manufacture. They are the present standard in rockets; e.g. the Shuttle main engine (SME) nozzles yield 99% of the ideal nozzle thrust (and the remainder is because of wall friction, not because of wall shape effect).

e. Annular and linear nozzles, designed to compensate ambient pressure variation, like the Aerospike nozzle. They are under development.

Choking is a compressible flow effect that obstructs the flow, setting a limit to fluid velocity because the flow becomes supersonic and perturbations cannot move upstream; in gas flow, choking takes place when a subsonic flow reaches M=1, whereas in liquid flow, choking takes place when an almost incompressible flow reaches the vapour pressure (of the main liquid or of a solute), and bubbles appear, with the flow suddenly jumping to M>1. Going on with gas flow and leaving liquid flow aside, we may notice that M=1 can only occur in a nozzle neck, either in a smooth throat where dA=0, or in a singular throat with discontinuous area slope (a kink in nozzle profile, or the end of a nozzle).

Let us consider the steady isentropic 1D gas dynamics in a CD-nozzle, with the perfect gas model (i.e. $pV=mRT$ and, $M \equiv v/c$ (where $c=\sqrt{\gamma RT}$ taking T=0 K as energy reference, $h=c_pT$ Conservation of mass, momentum, and energy, in terms of the Mach number, stands for the sound speed), become:

where logarithmic differentiation has been performed. Notice that, with this model, the isentropic condition can $T/p^{(\gamma-1)/\gamma}$=const, replace the momentum equation, so that differentiation of the isentropic relations for a perfect gas yields:

$$\frac{dT}{T}=\frac{\gamma-1}{\gamma}\frac{dp}{p}$$

$$\frac{T_t}{T}=1+\frac{v^2}{2c_pT}=1+\frac{\gamma-1}{2}M^2=\left(\frac{p_t}{p}\right)^{\frac{\gamma-1}{\gamma}}$$

Notice that, with the perfect gas model, γ remains constant throughout the expansion process. However, when the engine flow is composed of hot combustion products, real gas effects become important, and as the gas expands, γ shifts as a result of changes in temperature and in chemical composition. Maximum thrust is obtained if the gas composition is in chemical equilibrium throughout the entire nozzle expansion process. Choosing the cross-section area of the duct, A, as independent variable, the variation of the other variables can be explicitly found:

$$\left(1-M^2\right)\frac{\mathrm{d}T}{T}=(\gamma-1)M^2\frac{\mathrm{d}A}{A}$$

$$\left(1-M^2\right)\frac{\mathrm{d}p}{p}=\gamma M^2\frac{\mathrm{d}A}{A}$$

$$\left(1-M^2\right)\frac{\mathrm{d}M}{M}=-\left(1+\frac{\gamma-1}{2}M^2\right)\frac{\mathrm{d}A}{A}$$

$$\left(1-M^2\right)\frac{\mathrm{d}v}{v}=-\frac{\mathrm{d}A}{A}$$

Naming with a '*' variables the stage where M=1 (i.e. the sonic section, which may be a real throat within the nozzle or at some extrapolated imaginary throat downstream of a subsonic nozzle), and integrating from A to A^*, equations become:

$$\frac{T^*}{T}=\frac{1+\frac{\gamma-1}{2}M^2}{\frac{\gamma+1}{2}}\xrightarrow{T_t=T\left(1+\frac{\gamma-1}{2}M^2\right)}\frac{T^*}{T_t}=\frac{2}{\gamma+1}$$

$$\frac{p^*}{p}=\left(\frac{1+\frac{\gamma-1}{2}M^2}{\frac{\gamma+1}{2}}\right)^{\frac{\gamma}{\gamma-1}}\xrightarrow{\frac{T}{T_t}=\left(\frac{p}{p_t}\right)^{\frac{\gamma-1}{\gamma}}}\frac{p^*}{p_t}=\left(\frac{2}{\gamma+1}\right.$$

$$\frac{A^*}{A}=M\left(\frac{\frac{\gamma+1}{2}}{1+\frac{\gamma-1}{2}M^2}\right)^{\frac{\gamma+1}{2(\gamma-1)}}$$

In converging sections (dA<0):

- When the flow is subsonic (M<1→(1-M^2)>0): speed increases (dv>0), Mach-number increases (dM>0), but pressure and temperature decrease.
- When the flow is supersonic (M>1→(1-M^2)<0): speed decreases (dv<0), Mach-number decreases (dM<0), but pressure and temperature increase.

In diverging sections (dA>0):

- When the flow is subsonic (M<1→(1-M^2)>0): speed decreases (dv<0), Mach-number decreases (dM<0), but pressure and temperature increase.
- When the flow is supersonic (M>1→(1-M^2)<0): speed increases (dv>0), Mach-number increases (dM>0), but pressure and temperature decrease.

Area ratio: - Nozzle area ratio ε (or nozzle expansion ratio) is defined as nozzle exit area divided by throat area, $\varepsilon\equiv A_e/A_*$, in converging-diverging nozzles, or divided by entry area in converging nozzles. Notice that ε so defined is ε>1, but sometimes the inverse is also named 'area ratio' (this contraction area ratio is bounded between 0 and 1); however, although no confusion is possible when quoting a value (if it is >1 refers to A_e/A_*, and if it is <1 refers to A_*/A_e), one must be explicit when saying 'increasing area ratio' (we keep to $\varepsilon\equiv A_e/A_*>1$).

Converging-diverging nozzle: - A converging-diverging nozzle ('condi' nozzle, or CD-nozzle) must have a smooth area law, with a smooth throat, dA/dx=0, for the flow to remain attached to the walls. The flow starts from rest and accelerates subsonically to a maximum speed at the throat, where it may arrive at M<1 or at M=1, as for converging nozzles. Again, for the entry conditions we use 'c' (for chamber) or 't' (for total), we use 'e' for the exit conditions, and '*' for the throat conditions when it is choked (M*=1).

if the flow gets sonic at the throat, several downstream conditions may appear. The control parameter is discharge pressure, p_0. Let consider a fix-geometry CD-nozzle, discharging a given gas from a reservoir with constant conditions (p_t,T_t). When lowering the environmental pressure, p_0, from the no flow conditions, p_0=p_t, we may have the following flow regimes.

- Subsonic throat, implying subsonic flow all along to the exit.
- Sonic throat (no further increase in mass-flow-rate whatever low the discharge pressure let be).
- Flow becomes supersonic after the throat, but, before exit, a normal shockwave causes a sudden transition to subsonic flow (evolution *c*). It may happen that the flow detaches from the wall (see the corresponding sketch).
- Flow becomes supersonic after the

throat, with the normal shockwave just at the exit section (evolution *d*).

- Flow becomes supersonic after the throat, and remains supersonic until the exit,

Adapted nozzle, where exit pressure equals discharge pressure (evolution *f*). Notice that, as exit pressure p_e only depends on chamber conditions for a choked nozzle. The nozzle shall be expanded or over expanded. The supersonic mass-flow-rate and exit speed in the isentropic discharge through a nozzle are:

$$\dot{m} = \rho^* v^* A^* = \frac{p^*}{RT^*}\sqrt{\gamma RT^*}\,A^* = \frac{\gamma p^* A^*}{\sqrt{\gamma RT^*}} = \frac{\gamma p_t A^*}{\sqrt{\gamma RT_t}}\Big(\; \gamma$$

$$v_e = \sqrt{\frac{2\gamma RT_t}{\gamma - 1}\left[1-\left(\frac{p_e}{p_t}\right)^{\frac{\gamma-1}{\gamma}}\right]} = \sqrt{\frac{2\gamma RT_t}{\gamma - 1}\left[1-\frac{1}{1+\frac{\gamma-1}{2}M}\right.}$$

Although it is often said that m& is constant in a choked nozzle (critical flow-rate), what is meant is that the mass-flow-rate does not depend on back pressure (provided the flow becomes supersonic), but m& is almost proportional to chamber pressure.

The direct injection of steam into a process stream is a method of heating used in many process industries. The amount of research in this area however is limited to the nuclear industry. A project
involving both experimental work and numerical simulations was undertaken to better understand the dynamics of the direct contact steam condensing process, with the aim of creating a practical approach of modelling this process with CFD and designing an improved steam injection system.

The interface between the liquid and vapour is rapidly changing and contains both large and small surface features and bubbles, over which the heat and mass transfer takes place. To calculate the rate of heat and mass transfer the theory from previous work modelling flashing flows (Marsh, 2004) was used as a starting point. The interfacial area is the surface area between the vapour phase and the liquid phase over which the energy and mass transfer takes place. This is in effect the total surface area of the vapour bubbles and is expressed in terms of area per unit volume.

The approach used by Blinkov et al (1993) determined the number of bubbles and then calculates the radius of the bubble based on the local vapour fraction. For spherical bubbles, the interfacial area (Ai,b), and the local vapour fraction (a) are shown in equations respectively: -

$$A_{i,b} = 4\pi R_b^2 N_B$$

$$\alpha = \tfrac{4}{3}\pi R_b^3 N_B$$

combing these equations, we have an equation for interfacial area

$$A_{i,b} = 3\alpha / R_b$$

When considering flashing flows the bubble number density is determined from bubble nucleation theory. However, with the process of collapsing steam the bubbles are formed by the break-up of larger bubbles and slugs. As there is no information available for this variable for condensing flows, a constant bubble density per unit volume was assumed.

The driving force for the condensation of steam is the difference between the local liquid temperature and the liquid saturation temperature.

Figure 3: Steam Plume

The heat transfer coefficient between the liquid and vapour phases was calculated using the following equations;

$$Ja = \frac{c_{p,l}\rho_l \Delta T}{\rho_v i_{lat}}$$

$$Nu = \frac{12Ja}{\pi}\left[1 + \tfrac{1}{2}\left(\frac{\pi}{6Ja}\right)^{2/3} + \frac{\pi}{6Ja}\right]$$

$$h = \frac{k_l Nu}{2R_b}$$

The formulation for the heat transfer coefficient h is based on the Nusselt number Nu and the Jacob number Ja.

The energy transfer was assumed to act only across the interfacial area and thus the total energy transfer was calculated from the product of the driving force Δ T, interfacial area and the heat transfer coefficient. The total energy transferred was then

$$J_E = hA_i \Delta T_l$$

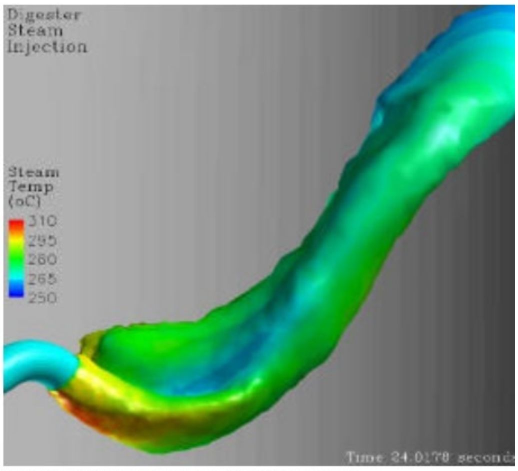


Figure 8: Steam Plume after 24 seconds.

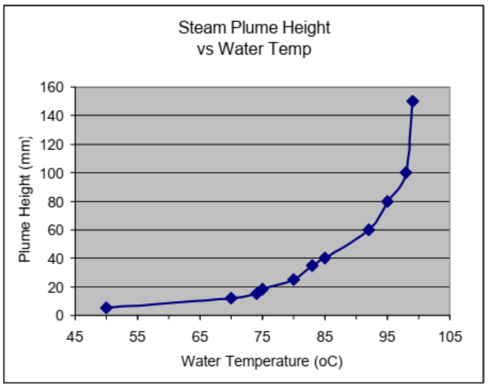
used as the source term (J_E) in the energy transport equation for each phase within the multiphase model in the following form

As the liquid cannot exceed the local saturation temperature without changing back to steam this source term was only considered to act when the liquor temperature was below the saturation temperature. The phase change from liquid to vapour was not considered to be significant.

$$J_M = \frac{hA_i \Delta T_l}{i_{lat}}$$

As the superheated steam reduces in temperature and reaches the local saturation temperature, the mass transfer process begins. The mass source term (J_M) being equal to the energy source term divided by the latent heat of condensation, where the steam temperature is equal to local saturation temperature.

The temperature of the steam and water were varied to gain an



understanding of the different vapour collapsing regimes and to better understand the relationship between the steam plume and the degree of tank mixing.

While holding the steam temperature and flow rate constant and varying the liquid temperature the height of the steam plume could be measured. This relationship is shown in figure and follows an exponential relationship.

This relationship was used as a means to determine a representative value for the bubble density allowing the correct interfacial area between the phases to be determined, completing the mathematical model of the condensing process.

These models allow us to estimate a large continuous plume with expansive thrust and the induced water flow to cause a significant thrust generation. Multiple nozzles can be used for thrust and steering purposes controlled through suitable high temperature valves.

CONCLUSION:

In many large, oil powered ships trading over long trading routes, the required fuel can claim 15% of the ship's displacement. In some trade routes, enough fuel for a round trip must be carried because of the non-availability of fuel in the destination port. Every time a ship leaves port, it must carry enough fuel to reach its next scheduled destination with at least a 25 percent reserve margin. This safety requirement can place a significant limitation on the ship's employment. If a ship must schedule an intermediate stop for fuel, the diversion can add a day to the voyage time, require the payment of additional port fees, and require payment for the services of tugs and fueling support vessels. A fuel call for a ship is not like stopping at a gas station off the interstate. An additional complexity in fuel management is the fact that there are limitations on maximum ship draft that vary depending on the time of year. Some ships have to reduce their cargo load to be able to load sufficient fuel to meet the requirements.

Finally, oil prices, availability and quality are not uniform throughout the world. It frequently requires the costly services of a dedicated department within a ship management company to optimize decisions with regard to when and where ships should buy their fuel. Based on naval experience and limited amounts of commercial experience, the public will accept nuclear ship port visits. While there are some rare ports that do not like naval ships to visit, their major concern is weapons load, not propulsion system. With the exception of isolated protests by tiny groups of activists, the port visits of nuclear-powered ships have been a cause for celebration and community welcome mats. The welcoming attitude has apparently been the same whether the ship was involved in revenue-producing international trade or military liberty.

The proposal is to do further research work to develop the dual loop first loop with sodium-potassium (NaK) alloy and second loop with a Lead-Bismuth(Pb-Bi) alloy on the nuclear fast breeder marine reactor working with solid metal alloy fuel element having breeding ratio of 1.4 and thermal efficiency exceeding 40% for the nuclear reactor for both civil and military application and develop a large strategic fleet of commercial carriers which is state own to serve as a national back bone in time of trouble and contingency.