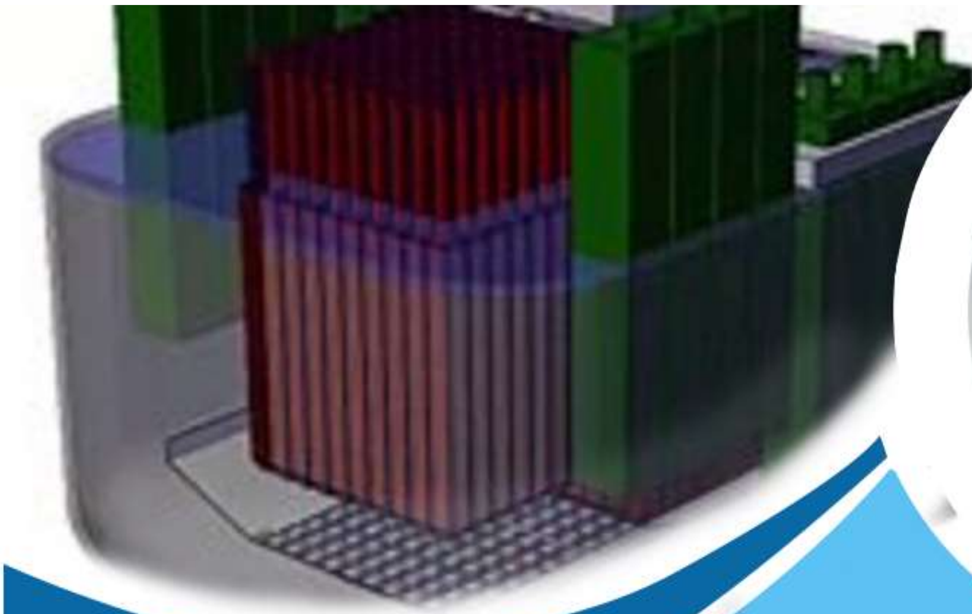

TEAM HERMETICA

STABLE SALT REACTOR

(Next Generation Nuclear Reactor)

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INTRODUCTION-

Nuclear energy has the potential to provide huge amounts of power to the grid but funding and long build times continue to derail its process. The energy released during nuclear fission can be harnessed to make electricity with a nuclear reactor. Nuclear energy can only make a real contribution in spurring economic development if its cost falls dramatically. History has shown that unless nuclear energy can be produced at a lower cost than fossil fuels, the world will continue burning fossil fuel. A nuclear reactor generates more than 800 billion kilowatt hours of electricity each year and produces more than 55% of the nation's electricity emission. This avoids more than 470 million metric tons of carbon each year, which is equivalent to removing 100 million cars from the road. Nuclear technology has a wide range of applications. **A new development in the nuclear industry is the concept of passive safety. This means that in the event of a failure leading to accident conditions, the reactor will naturally revert to a safe shutdown condition and maintain that condition with minimal operator intervention.** So, the most effective method to enhance the use of nuclear technology is eliminating the cause of hazard rather than managing them.

Stable salt reactor is the solution to produce highly efficient, low cost energy with the growing energy demand nowadays. The stable salt reactor with its small and simple design aims to deliver cleaner, safer and low cost energy than traditional nuclear alternatives. The reactor would not need expensive containment structures and components to mitigate radioactive releases in accident scenarios. The design of stable salt reactors would preclude the type of widespread radiological containment that occurred, following the Chernobyl or Fukushima accident, as the hazardous airborne isotopes are chemically bonded.

For the countries that have already successfully employed nuclear, stable salt reactors offer a key additional benefit to meet environmental stewardship goals, reduce costs and strengthen public confidence in nuclear technology.

It will form a critical part of the massively expanded global nuclear power generation system that is needed if the world aims to truly decarbonize its power production.

PAST TECHNOLOGY-

The first nuclear reactor was designed to use bombs to generate 239Pu. After that these reactors are used for different purposes like electricity generation, propelling ships for generating isotopes and supplying heat. The first nuclear power station to produce electricity by using heat from the splitting of uranium atoms began operating in the 1950s. There are different types of frequently used nuclear reactors such as pressurized water reactors (PWR), Gas cooled reactors, Fast breeder reactors, small modular reactors (SMR) and many more. Today most people are aware of the important contribution nuclear energy makes in providing a significant proportion of the world's low-carbon electricity. The principles for using nuclear power to produce electricity are the same for most types of reactor. The energy released from continuous fission of the atoms of the fuel is harnessed as heat in either a gas or water, and is used to produce steam. The steam is used to drive the turbines which produce electricity (as in most fossil fuel plants).

The conventional nuclear reactors use solid fuel pellets that require high internal pressure and release dangerous gases. The Zircaloy tube reacts with water and produces explosive hydrogen. The renewable sources- solar and wind can be installed only in areas enriched with it.

The stable salt reactor is based on the molten salt reactor, which can be traced back to the 1960s. The molten salt reactors use fluoride fuel salt that act as both fuel and coolant. There were plentiful benefits of the molten salt reactor such as small containment, high heat capacity, and high temperature. But there were certain drawbacks like material degradation, tritium production and remote maintenance were the reason that their use was minimized.

So, in order to overcome these challenges and improve the earlier technology, a Stable salt reactor is introduced. The small size and intrinsic safety make this reactor much less costly to build and operate than the other conventional reactors.

DESCRIPTION -

The stable salt reactor is based on the fundamental safety and simplicity of the molten fuel in the standard nuclear fuel tubes.

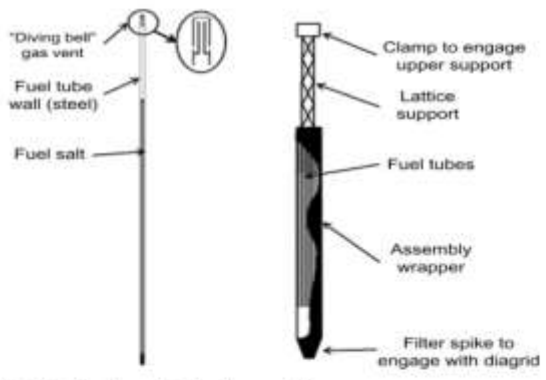
Fuel salt-

The fuel salt is a eutectic mixture of 60mol% of NaCl with 40% mixed uranium, plutonium and lanthanide trichlorides. The initial fuel for the reactor comes from the stocks of pure PuO_2 from plutonium uranium redox extraction (PUREX) reprocessed conventional spent fuel, mixed with pure depleted uranium trichloride. Being a trichloride, it is much more thermodynamically stable than the corresponding fluoride salts. It can therefore be maintained in a strongly reducing state by contact with sacrificial nuclear grade zirconium metal added as a coating on, or an insert within, the fuel tube.

Composition (mol %)	60%NaCl, 20% $PuCl_3$/ 20% (UCl_3/$LnCl_3$)
Melting point	730 K
Boiling point	~1837 K
Density	4.1690-9.014*10^{-4} g/ml.K
Thermal conductivity	0.5 W/m.K

Fuel tubes-

The fuel tubes that are immersed in the reactor tank are made of Nimonic PE16 stainless steel and they do not react with the fuel salt. Since the tubes will be exposed to very high neutron flux and suffer high damage (DPA) levels, estimated at 100-200 DPA over the tube life, highly neutron damage-tolerant steels such as HT9 or PE16 are used for the tubes.



Single fuel tube and fuel tube assembly.

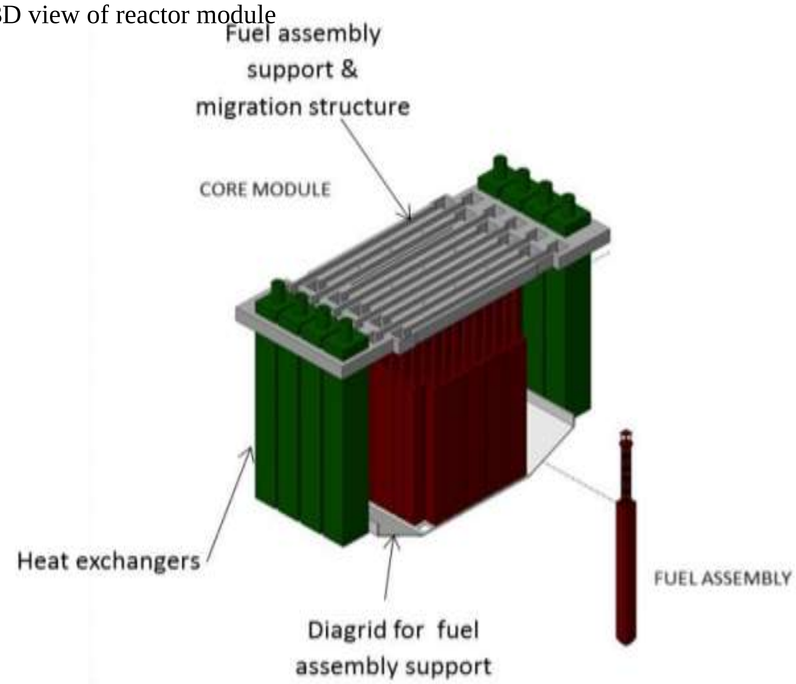
Coolants-

<u>Primary coolant</u>: The primary coolant salt in the tank is composed of 42mol% ZrF_4, 10% NaF, and 48% KF. The zirconium is not a nuclear grade and still contains ~2% hafnium. The flow rate of the coolant across the tube is 1m/s. The coolant salt is also non-corrosive to standard steel and thus the reactor tank, support structure, and heat exchangers can be constructed from standard 316L stainless steel.

<u>Secondary coolant</u>: The secondary coolant salt is identical to the primary coolant but as the primary coolant becomes radioactive due to neutron activation, the secondary coolant transfers heat out of the reactor building. A small positive pressure in the secondary coolant loop ensures no leakage of radioactivity out of the reactor.

Composition (mol %)	48% KF, 10% NaF, 40% ZrF_4/2% ZrF_2
Density	2770 kg/m^3
Specific heat capacity	1050 J/kg.K
Kinematic viscosity	1.731026 m^2/s
Thermal conductivity	0.7 W/m.K
Inlet temperature	450-460C

3D view of reactor module

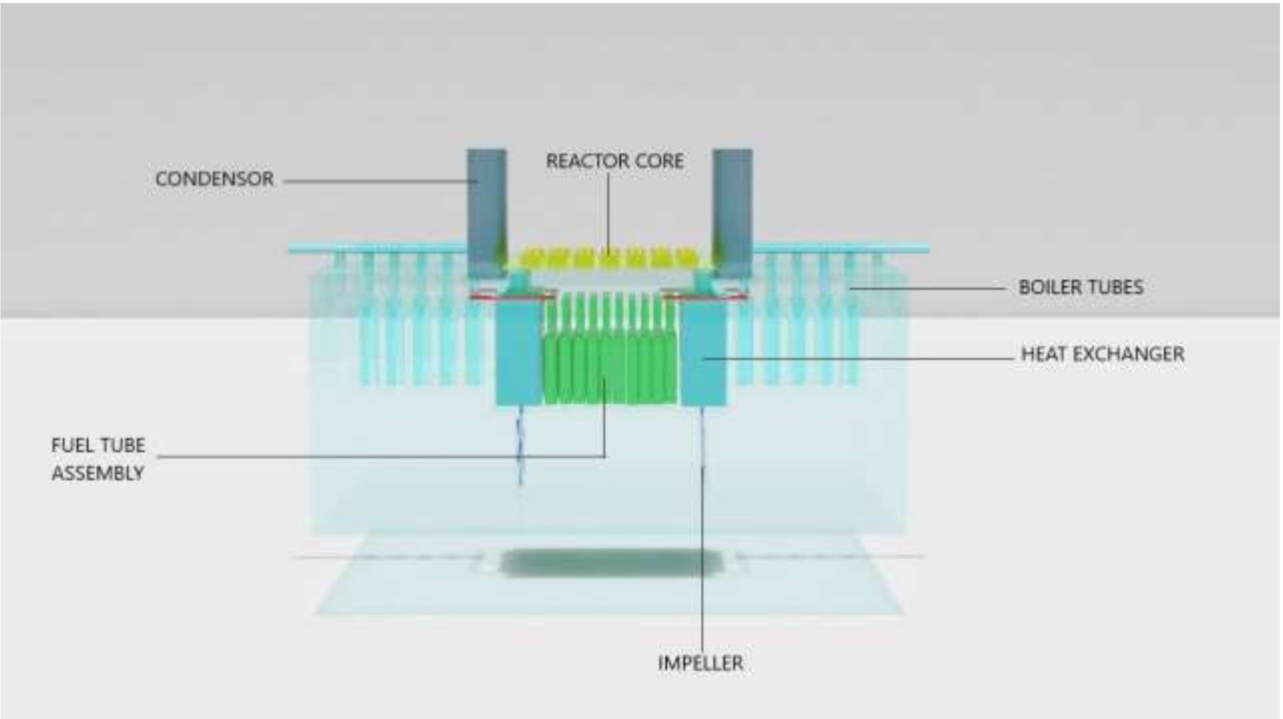


REACTOR DESIGN-

The basic unit of the reactor core is the fuel assembly. Each assembly contains a square 18*21 hexagonal close-packed array of 10 mm diameter fuel tubes with 1 mm helical wire wrap filled to a height of 1600 mm with fuel salt. The tubes have diving bell gas vents at the top to allow fission gasses to escape. The region of the assembly above the fuel tubes is a lattice structure that is narrower than the main part of the assembly, allowing space for instrument thimbles to be inserted between the fuel assemblies. At the top the assembly has a spring-loaded apparatus that positively locates the assembly into the upper support grid, while permitting the springs to be compressed to disengage the assembly from the upper support grid. Each module contains 10 rows of 10 fuel assemblies, upper support grid, lower diagrid, heat exchangers, pumps, control assemblies, and instrumentation. Each module has a thermal output of 375 MW. The modules (without fuel assemblies) are pre-assembled into the stainless-steel tank and delivered to the construction site as single road-transportable components. They are placed in concrete- and steel-lined pits below grade level.

The upper part of the reactor consists of an argon containment dome, incorporating two crane type systems, a low load device designed to move fuel assemblies within the reactor core, and a high load device designed to raise and lower fuel assemblies into the coolant and to replace entire modules should that be necessary.

The basic designing outline of the reactor is given below-



Stable salt reactor

WORKING-

Stable salt reactor is a fast reactor with no moderator. The fuel salt is held in vented fuel tubes. Venting is safe because the dangerous fission products such as cesium and iodine form stable salts instead of remaining in the elemental form as happens in the conventional reactors. The tubes are bundled into fuel assemblies and are held in the support structure which forms the reactor modules. The tank is filled with a safe molten salt coolant which is non-reactive and is not pressurized. The boiler tubes provide heat for the initiation of the fission reaction inside the fuel tubes. As fission occurs, heat is released and is absorbed by the primary coolant. The primary coolant passes heat to an identical secondary coolant through heat exchangers immersed in the reactor tank. Then, the secondary coolant system takes up the heat and thus, the heat can be used to produce electricity, hydrogen or other industrial processes.

The reactor controls are exceptionally simple. Temperature and neutron sensors are provided around the core. Reactivity is controlled primarily by the refueling system. Fuel assemblies are simply moved sideways out of the core and replaced with fresh fuel assemblies. An emergency shutdown is provided and the reactor is continuously cooled so as to avoid overheating in an accident situation.

Not all gaseous fission products form non-volatile stable salts in molten salt fuel like iodine and cesium. The noble gases xenon and krypton are produced and there are hundreds of other possible volatile species. But those gases immediately encounter the cooler walls of the tube above the level of the fuel salt where the temperature is the same as the coolant. Since the gas flow is extremely slow, a few ml per day, there is plenty of time for the gases evolved to condense on the cooler walls. The result is that only Xe, Kr, Cd and $ZrCl_4$ are released in significant quantities. None of these are hazardous radioisotopes – Xe-137, which decays to hazardous Cs-137, decays almost entirely while still in the tube gas space.Thus, the substance that decomposes remains in the fuel tube and rest harmless noble gases can be released to the atmosphere.

Refueling

The fuel assemblies in the core are arranged in rows of 10 aligned along linear support structures. Refueling involves simple stages:

A spent fuel assembly is lifted from its anchoring point at one end of the row and moved laterally, still immersed in the coolant salt; to a storage location at the extreme end of the row with the help of the piston. Similarly, the new fuel assembly is added with the same process. It remains there for 3-6 months until its decay heat has fallen to the level where it can be lifted from the coolant, allowed to freeze, and then moved into dry cask storage. The coolant stored in the tank can be replaced by the vacuum pump and new coolant is added through the mesh using the refueling machine

Disposal of Nuclear Waste

Spent fuel from the reactor can be reprocessed. As the fuel is already in a salt form, this is far simpler than in the case of oxide fuel. The spent salt fuel is melted and reprocessed directly by electrolysis. This produces four streams of product:

- A metallic waste form containing the fuel tube metal plus deposited noble metal fission products, including technetium.
- A pure uranium metal fraction which can be stored for future use in breeder reactors.
- An impure uranium/plutonium/higher actinide/lanthanide fraction which can be used as a fuel for the stable salt reactor with no further purification.
- A mix of actinide free fission products for storage and useful applications or disposal. Thus, the process will no longer produce long-lived actinide waste.

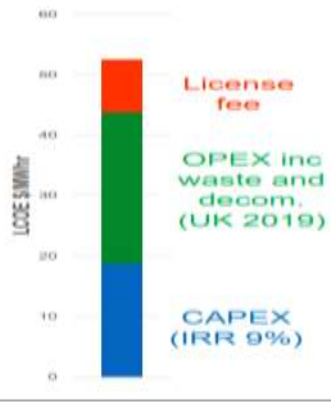
Electricity generation system and Grid Reserve

The reactor has an output temperature of ~600°C. The heat, when not needed for electricity production is stored in Grid Reserve (molten salt energy store) which can hold eight hours of continuous reactor output at 2.5GW thermal. This is mature technology from the concentrated solar power industry and can be used to store energy at a grid scale from any heat source that can provide the 550-600°C temperature required. Conventional nuclear (300°C) cannot use this technology.

The system allows a 2.5GW thermal output reactor facility operating continuously to produce electricity, for example, 2GW of electricity for eight hours a day, zero electricity for eight hours and 1GW for eight hours, or select one of many alternative power production profiles.

This takes the reactor out of the fast disappearing and relatively low-value baseload market and allows it to provide a zero-carbon complement to intermittent renewable energy sources. The economic value of this variable generation capability is far greater than the additional cost of the heat store, which adds just £3 per MWh to the levelized cost of electricity

Cost Estimation



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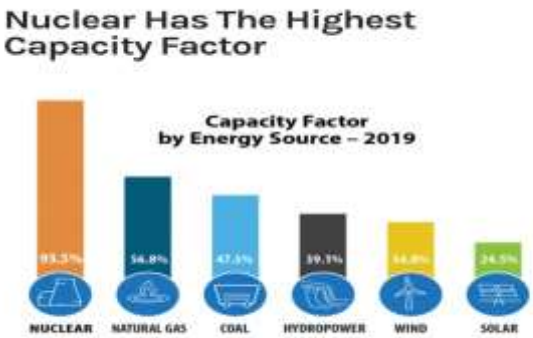
The overnight capital cost of the stable salt reactor is estimated at $1,950/kW by an independent UK nuclear engineering firm. For comparison, the capital cost of a modern pulverized coal power station in the United States is $3,250/kW and the cost of large-scale nuclear power is $5,500/kW. Further reductions to this overnight cost are expected for modular factory-based construction. This low capital cost results in a levelized cost of electricity (LCOE) of $44.64/MWh with substantial potential for further reductions, because of the greater simplicity and intrinsic safety of the reactor.

APPLICATIONS-

- The reactor has wide application in the field of electricity production on a large scale.
- Radioisotopes, nuclear power process heat and non-stationary power reactors have essential uses across multiple sectors, including consumer products, food and agriculture, medicine and research.
- The utilization of the nuclear non-electric process heat has potential in four areas: desalination of seawater and wastewater, district heating of residential and commercial buildings, industrial process heat supply and fuel synthesis.
- Co-60 has a convenient half-life and gamma energies to be used in hospitals as a principle form of radiation therapy.
- Nuclear technology is also very useful in pest control and reducing the number of necessary fertilizers.



ADVANTAGES-

- It is highly profitable at electricity prices lower than those achievable by fossil fuels.
- The cost is estimated to be 1/3rd of the conventional nuclear reactors.
- The simplicity of design and the low component count is one of the primary advantages.
- It helps to clean up the long-lived radioactive waste.
- It is able to use fuel that is of very low purity (plutonium) contaminated with uranium and lanthanides.
- It eliminates instead of managing fundamental hazards.
- It has a small size and large production.
- The intrinsic safety by the refuelling process prevents certain hazards.
- All welds and joints in boiler tubes are outside the coolant salt avoiding the chance of steam leaks into the coolant.
- It is highly effective and self-controlling.
- No pressure build-up is required inside the reactor.

DISADVANTAGES-

- Salt concentration should not be changed.
- Trichlorides salts should be used as other salts may be corrosive to fuel tubes.

FUTURE ASPECTS-

With a total capacity of 382 GW(e) from 441 nuclear reactors in 30 countries and an accumulated experience from approximately 15000 years of operation, nuclear energy has evolved to an industrially mature and reliable source of electricity and a key component in the global energy economy. Nuclear power is the second-largest source of clean energy after hydropower but has only a small contribution to energy production due to its cost and dangerous product formation.

The world's energy demand is expected to grow by one-third by 2040. There is a race to keep up with this demand as billions of people strive to improve their quality of life through increased access to essential services, nearly all of which require electricity. In the non-OECD, growth is more evenly split between renewable, nuclear and hydro. Nuclear output grows rapidly, averaging 7.8% p.a 2010-30, as China, India and Russia pursue ambitious expansion programmes.

So, the stable salt reactor that is cheaper, safer and cleaner than other conventional reactors can help to meet the future energy requirement and thus can increase economic development with its high-capacity factor. There is an exciting competition developing for this concept of a stable salt fuelled reactor and the alternative use of conventional pumped molten salt adopted. The reactor produces almost double output then than the other conventional reactor and thus will lead to the growth of nuclear technology in future. The stable salt reactor has the potential to access a market of over 1300GWe by 2040.