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The Modular SSR Design

While the fundamental innovation of using ultra-safe molten fuel in simple fuel assemblies is the key factor behind the advantages of the Stable Salt Reactor, a number of other substantial innovations have been built into the design.

Pool design

This is a major driver of most advanced reactor designs, ensuring that loss of coolant through leaks cannot expose the core. It has been adopted for the SSR.

Passive cooling

Even if the coolant cannot escape, it can overheat even if the reactor is shut down. All reactors have to be able to pass the decay heat from a shut-down core to a heat sink and most current reactors require active pumped water systems to do this. Advanced reactors seek to do this entirely passively. The ideal is to passively lose decay heat to the inexhaustible heat sink that is the atmosphere. Unfortunately generally only reactors with a low power/volume ratio can achieve this. The Stable Salt Reactor combines its operation at the high temperatures allowed by using molten salt coolant with a novel, patented way to pass heat from the reactor vessel to the atmosphere to achieve entirely passive air cooling for a high power but compact reactor.

Semi-continuous refuelling

Most reactors are refuelled at long intervals, often 18 months. This is a major operation taking the reactor offline for many weeks. The large amount of fresh fuel added makes it necessary to "hold down" the excess nuclear reactivity until most of it has burned away. The design of the SSR was explicitly made so that small, regular, additions of fuel could be made so the reactor never has significant excess nuclear reactivity and does not need safety critical engineered reactivity control systems.

Modularity

Conventional large reactors are substantially built on site which is slow and expensive. That has been a major factor in making them too expensive to be economical. There is a move today towards modular construction of reactors so that complete reactors can be built in factories and shipped to the site for installation. Most modular reactors are relatively small, with several reactors having to be combined into a single installation to achieve necessary scale. There are serious arguments about whether this approach will genuinely reduce total costs. The SSR is factory constructed but the modularity philosophy is different. By opting for rectangular core geometry instead of the conventional cylindrical core, the SSR can be built in a factory at any scale from 300MWe to 1200MWe using varying numbers of identical 150MWe modules. The resulting reactor is small enough to be shipped by road, even the GW scale reactor, due to the much higher power density that the molten salt fuel/molten salt coolant makes possible.

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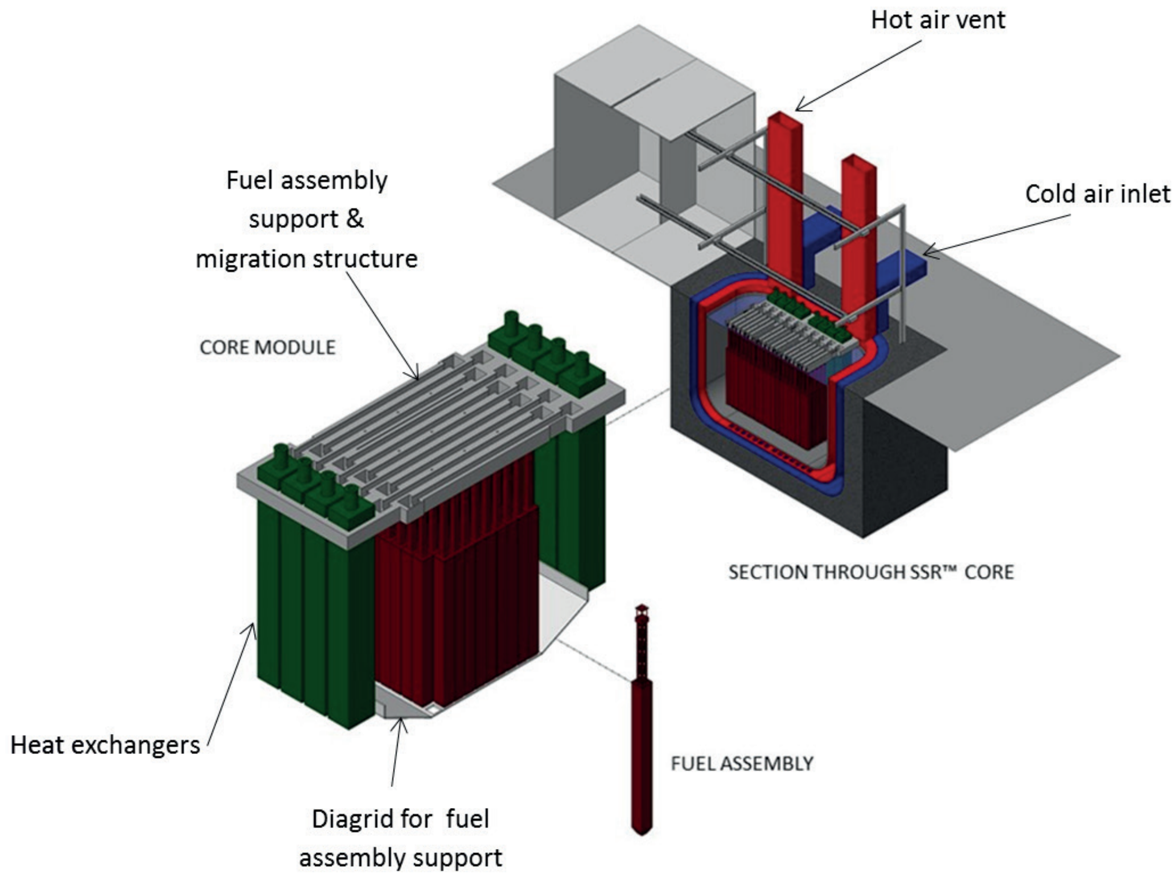
Reactor structure and modularity

The reactor, illustrated in the figure, consists of a core of essentially conventional (though salt fuel filled) fuel assemblies in a tank of coolant salt. Above the tank is an argon containment dome containing a crane system, airlocks, and gas cooling apparatus. The coolant salt is pumped through heat exchangers and then through the core. It passes its heat to a secondary coolant loop which transfers the heat to an external power conversion system. The outlet secondary coolant temperature is 570°C making it suitable for process heat as well as power generation.



The basic reactor module is a core segment measuring 2m x 2m together with its support structures, fuel assembly handling equipment, instrumentation, control assemblies, pumps and heat exchangers, totalling 2m x 5m. Two or more of these modules are mounted in a single tank forming a rectangular core of 2m width and expandable length. A two module unit has an electrical capacity of 300MWe which can be expanded readily in 150MWe increments up to 1200MWe. The tank containing the core assembly is 5m wide x 4.5m deep with a length from 6m (300MW) to 18m (1200MW).This complete lower tank structure is road transportable. The upper tank structure is also (separately) road transportable.

The complete reactor is installed, on site, in a concrete lined pit. Air convection in the space between the concrete lining and the reactor tank, combined with a unique finning structure to make maximum use of radiative heat transfer, is

Fuel salt composition	$NaCl/UCl_3/PuCl_3$ (60/20/20)
Fissile content fresh assembly	20mol% reactor grade plutonium
Fuel salt M. Pt.	487°C
Fuel salt operating temp	500-1121°C
Fuel salt redox control	Sacrificial zirconium
Fuel salt power density	150kW/l
Coolant composition	$ZrF_4/KF/NaF$ (42/48/10)
Coolant melting point	385°C
Coolant operating temp	450-650°C
Coolant redox control	ZrF_2/ZrF_4 couple
Coolant flow velocity in core	1.7m/s
Reactor pressure	Atmospheric pressure
Coolant pump pressure	0.25-0.5 bar

sufficient to passively remove decay heat from the reactor after shutdown while keeping the concrete cool during normal reactor operation. This convection is facilitated by dividing the space into incoming cool air and outgoing heated air which is vented via chimneys to atmosphere.

All metal components in contact with the molten salts are standard nuclear grade steels. The salt chemistry has been selected to make use of such materials practical.

Core composition and geometry

The reactor core comprises an array of 200mm square fuel assemblies each containing 378 fuel tubes of 10mm external diameter in a hexagonal array with 1mm spiral wrap wire used to separate the tubes. The assembly is contained within a steel wrapper. The assembly is thus similar in construction to conventional fast reactor fuel assemblies and is fabricated from similar neutron tolerant stainless steels such as PE16. The fuel tubes are 2m long and are filled to a depth of 1.6m with fuel salt comprising 60mol% NaCl plus 40mol% of a mixture of uranium and plutonium trichlorides. The chlorine is of natural isotopic composition. Each fuel tube is sealed at the top with a "diving bell" gas vent.

The core contains 200 fuel assemblies in rows of 10 assemblies. They are secured at the bottom in a diagrid where filter spikes on the base of the assembly locate in holes in the diagrid. They are secured at the top via a spring loaded top fitting that positively locates into support bars across the reactor tank. Each row of 10 assemblies allows assemblies to be moved along the row using a purpose build fuel transfer module with fresh assemblies added on one end and spent assemblies removed from the other end. There is thus a gradient of fissile burnup along the row. Alternate rows migrate in opposite directions so as to provide a relatively uniform fission rate across the reactor core.

Fuel management

Fresh fuel assemblies are constructed from pellets of fuel loaded into fuel tubes in the solid form exactly as for oxide fuel pellets (though without the need for precision sizing and spring loading). The assemblies arrive at the reactor in this solid fuel form and are lowered into the reactor tank at a sufficient distance from the core to ensure minimal fission activity. The pellets melt by heat conduction and convection from the coolant salt and are only moved into the core when fully melted.

After traversing the core, the spent fuel assemblies are moved to the periphery of the tank where they are stored until their decay heat has fallen to a level where gas or air convection will maintain the fuel in the frozen state. They are then lifted from the reactor tank, allowed to freeze and then moved to the interim storage location at the reactor site.

Interim fuel storage is in dry flasks, below ground level with passive convective heat removal to the atmosphere. Spent fuel can be stored indefinitely and transferred eventually to a geological repository. However, the salt based nature of the fuel permits its relatively simple reprocessing by pyrochemical methods so the preferred option is transport to a central reprocessing facility (in fuel transport casks similar to those in current use) followed by quantitative recycling of all actinides into fresh fuel. The two waste streams from this reprocessing would be a metallic waste form (predominantly stainless steel) containing the noble metal fission products including 99Tc and a fission chloride salt waste form which would form a glass on cooling and could be stored in suitable metal containers for the 300 years necessary for it to decay to a near inert state.

Reactivity Controls

The neutronic parameters and power density of the reactor have been selected so that the reactor will render itself subcritical should the coolant temperature rise to 830°C, a tolerable temperature for the stainless steel components. As a result of this the reactor can load follow to a substantial degree. No control rods or other reactivity control devices are required during normal operation. Shut down is achieved by use of steel clad boron carbide control blades inserted between rows of fuel assemblies. Backup emergency shutdown is by addition of sodium fluoroborate to the coolant salt.