Salt-cooled High-temperature Reactors

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Background

Molten salt cooled reactors (also known as Fluoride salt-cooled High-temperature Reactors – FHR) offer a number of significant advantages compared to currently operating LWRs. High temperature operation allows achieving high thermodynamic efficiency of power conversion using advanced power cycles, such as supercritical CO₂, as well as a possibility of using nuclear heat directly to drive industrial processes, production of synthetic fuels, such as hydrogen or for district heating of areas located particularly far away from the heat source.

Furthermore, high heat capacity of molten salts, their low operating pressure (despite high temperature) and high solubility and retention of otherwise volatile fission products would allow the salt-cooled reactors to avoid complicated and costly safety systems which plague the economics of LWRs.

While not as attractive as the classical molten salt reactors with fuel dissolved in the molten salt in terms of fuel cycle and operational flexibility, salt-cooled reactors still retain their major advantages in safety and economics mentioned above. Physical separation of molten salt coolant from the fuel also allows tighter and more convenient coolant chemistry control which would allow addressing the structural materials corrosion problem – the most challenging issue of classical molten salt reactors.

Multiple projects are currently under way around the world aiming at the development of salt-cooled reactors, most notably, a multi-billion project led by the Shanghai Institute of Applied Physics in China and Kairos Power – a privately financed company established as a result of over a decade long support of salt-cooled reactors development research by the US DoE. In the UK, the Engineering and Physical Sciences Research Council (EPSRC) sponsored a project led by the University of Cambridge aiming at examining to what extent the British Advanced Gas-cooled Reactor (AGR) technologies can be applied to speed up the development of salt-cooled reactors.

Proposal 1: Moderator choices for FHR

All FHR designs that have been examined so far assumed the presence of graphite in their cores in order to provide the core structure, or neutron moderation, or both. It has been known from operational experience with graphite cores that the graphite undergoes dimensional changes with irradiation which are challenging to predict and model, but which eventually lead to cracking and, when it becomes too extensive, ultimately limit the lives of graphite cores.

In the course of the EPSRC project on FHR leveraging AGR technologies, it was discovered that some of the considered core configurations with high power density and stable neutronic behaviour had minimal or no graphite at all. Eliminating graphite could be a major advantage, potentially simplifying the construction, maintenance and extending lifetime of the core. The neutronic, thermal-hydraulic and safety performance of such cores without graphite have never been assessed previously. The
objective of this project is to develop computational analysis model for graphite-free FHR and identify the most promising configuration (a combination of geometry and materials) which would maximise the core power output and fuel burnup, while meeting all the major safety limits criteria.

Proposal 2: Safety Case for AGR-like FHR

AGRs are exceptionally safe reactors due to their low core power density, large core thermal inertia and slow rate of depressurisation by design even in the worst-case loss of coolant scenarios. Therefore, loss of fuel integrity and release of fission products from AGRs is considered “not credible” by the UK regulator. The only conceivable scenario for fuel distortion is a failure of refuelling mechanism with associated drop of a fuel stringer assembly into the core. As a consequence, only some AGRs are allowed to refuel during operation at lower power.

If CO₂ coolant is replaced with low pressure, high-density, high-heat capacity coolant such as molten salt, the assembly drop during refuelling may no longer be an issue. Furthermore, the reactor would retain, and possibly even enhance the passive safety features of AGRs making the core completely meltdown-proof. Elimination of severe accident scenarios from the safety case could relax the requirements on safety systems, while simultaneously allowing for improved economic performance due to more compact (higher power density) core. This project will investigate the possibility of eliminating the core damage of AGR-like FHR under a range of limiting accident scenarios.

Proposal 3: Flexibility of FHR Fuel Cycle Options

Currently, most salt-cooled reactor design studies focused on conventional low-enriched UO₂ fuel and once-through (open) fuel cycle. Although this mode of operation can be argued to improve the proliferation resistance, other Gen-IV goals such as sustainability of fuel resource base and waste management cannot be substantially improved without recycling of actinides and high conversion ratio (CR) reactor designs. Some FHRs (e.g. Kairos) rely on high-temperature TRISO particles fuel which is particularly difficult (if not impossible) to reprocess.

AGR-like FHR, on the other hand, uses conventional pin-type fuel, for which reprocessing techniques are widely available and have been practiced on industrial scale. The objective of this project is to investigate alternative closed fuel cycle options for AGR-FHR designs with the goal of achieving either very low CR (actinide burner) or very high CR (potentially breeder). A range of recycling options will be examined: e.g. recycling Pu only or Pu + MA, as well as single-pass vs multi-recycling options. An impact of closed fuel cycle operation on the core performance characteristics such as maximum achievable power density within the acceptable safety limits will also be assessed.

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