Small Modular Reactors – What, Why and When?

Modular Stable Salt Reactors - a simpler way to use molten salt fuel

Ian Scott M.A., Ph.D
SSR Development Team

Advisory Board

Tim Abram
Westinghouse Professor of Nuclear Fuel technology, University of Manchester

Derek Fray
FRS, FR Eng, Director of Research, Cambridge University

Paul Littler
Nuclear Technical Director, Atkins Ltd

Tony Roulston
Lecturer Nuclear Energy, Cambridge University, former MD Rolls Royce Nuclear

Paul Madden
FRS, Provost Queens College Oxford

Nial Greeves
Head of Nuclear, Fraser-Nash Consultancy

Development Partners

ATKINS
Neutronics Simulations, Corrosion and Heat Transfer Experiments

The University of Manchester

Institution of Mechanical Engineers
Prototype Fuel Assembly Fabrication and Manufacturing Reviews

Wilde
Computational Fluid Dynamic and Heat Transfer Simulations

Nuclear AMRC

FRAZER-NASH
Licensing & Controls Support (C&I)

SOLID SOLUTIONS
Supporting Solutions Excellence

Key Claim Validation

CAD Modelling

Plant Cost Estimating & Safety Assessments

Venue Use & Communication Support
The Future of Nuclear Energy

Figure 8.4 - Global installed capacity by source in the New Policies Scenario

- New capacity additions
- Existing capacity

Renewables, Gas and oil, Nuclear, Coal
Nuclear Energy is too Expensive

OVERNIGHT CAPITAL COST OF NUCLEAR REACTORS
(constant 2014 $, by date of operation)

$ per kW

Coal 2016
Gas 2016

Actual US costs from Koomey & Hultman (2007)
The Basic Hazards of Nuclear Reactors:

- Volatile Caesium and Iodine Gasses
- High Pressures in Reactor Core to drive release

MOLTEN SALT FUEL ELIMINATES BOTH HAZARDS
Aircraft Reactor Experiment decision to abandon simple static fuel salt concept has been the basis of every MSR design from 1950 to 2013.
Basic Stable Salt Reactor Design

- Top anchor assembly
- Corner post
- Lattice support
- Fuel tube gas plenum
- Fuel tube fuel salt
- Assembly wrapper
- Assembly spike/coolant filter

Molten salt primary coolant
Molten salt secondary coolant
Review conceptual design against UK SAP’s (Safety Assessment Principles) from Office of Nuclear Regulation

Carry out HAZOP 0 analysis identifying essential structures, systems and components required for safe operation

Calculate approximate capital cost of the nuclear and electrical generator islands of an Nth of a kind Simple MSR
Stable Salt Reactor Capital Cost

OVERNIGHT CAPITAL COST OF NUCLEAR REACTORS
(constant 2014 $, by date of operation)

- No high pressure systems in the reactor
- Few engineered safety systems
- Few components and fewer moving parts
- Hazards needing massive containment eliminated

Actual US costs from Koomey & Hultman (2007)

Coal 2016
Gas 2016
UK on-site construction
Modular SSR construction

- Core module 150MWe
- Up to 8 modules
- Road transportable
Fuel Management

- Rectangular core allows counter-flow migration of fuel assemblies while on power
- Spent fuel cooled in reactor until it will freeze on withdrawal

Fresh fuel inserted

Spent fuel stored then removed
Modular SSR construction

- Core module 150MWe
- Up to 8 modules
- Road transportable
- Passive air cooling for decay heat even at 1200MWe
Modular SSR construction

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- 1200MWe reactor just 5m x 4m x 18m cannot handle decay heat by air convection – even with fins added
- High temperature (~750°C) makes thermal radiation the dominant heat loss mechanism
- Large surface area “thin fins” collecting radiant heat allow air convection to be effective
Modular SSR construction

- Core module 150MWe
- Up to 8 modules
- Road transportable
- Passive air cooling for decay heat even at 1200MWe
- Output temperature 650°C – heat storage
Energy Storage

Secondary coolant $\text{ZrF}_4/\text{NaF}/\text{KF}$
Melting 385°C Output 600-650°C
Drives superheater and reheater stage of boiler

Solar salt heat store to drive evaporator stage of boiler

Reactor operates at constant power 24/7 but electricity generation can be varied over day from 0-200% of reactor power
Modular SSR construction

- Core module 150MWe
- Up to 8 modules
- Road transportable
- Passive air cooling for decay heat even at 1200MWe
- Output temperature 650°C – heat storage
- Fuelled by low purity plutonium/actinides
Reprocessing of spent oxide fuel and spent fuel from the SSR

- Chlorine decladding and HF conversion converts zircalloy into SSR coolant salt and HCl
- Patented electrochemical reduction converts UNTREATED pellets to molten uranium alloy
- Patented electro-refiner separates pure uranium from U/Pu/Lanthanide alloy ready for use as SSR fuel
- Actinide free waste streams
  - Noble metal alloy
  - Lanthanide metal alloy
  - Other fission products for vitrification
Advantages of the Stable Salt Reactor

- Credible capital cost estimate lower than coal
- Can vary electricity output from zero to 200%
- Intrinsically much safer than uranium oxide fuel – liability limit and proximity to population for CHP
- Passive decay heat removal to air
- Passive shut down even if all control systems fail
- Modular, road transportable, rapid construction
- Consumes existing plutonium stock
- Consumes long lived waste from existing reactors without costly THORP and MOX plants
The Market Opportunity for Low Cost Nuclear Energy

Figure 8.4  Global installed capacity by source in the New Policies Scenario

- $7000 billion
- $5000 billion

International Energy Agency’s World Energy Outlook 2015
• Molten salt chemistry control allowing use of standard steels without corrosion
• Rectangular counter-flow reactor core design
• Passive air cooling for modular reactor
• Simple cheaper oxide fuel reprocessing
• 7 other patents
• Major opportunities for supply chain partners to develop IP

Feb 2014 > Master patent on un-pumped molten salt fuel - Granted in UK, pending in PCT nations
Why the UK?

- Moltex Energy is a UK company
- Supportive government and public opinion
- Regulatory system compatible with non LWR
- Large need for new cost effective generation
- 120 tonnes of plutonium
- Experience in reprocessing and no local support for geological repository
- Vendor capability sold off so little “sunk capital”
- Good base for international sales of reactors
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Thank You