Postgraduate Education in Criticality Safety: The UK Approach

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NSQEP Shortage in the UK

A generational gap in recruitment

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Many experienced staff approaching retirement

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'New build' looming

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Need more personnel!

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NSQEP Shortage in the UK

- But new (and experienced) personnel need training…
- Whilst industry may have their own (very intensive) training programmes
- What about new graduates,
- or career changers,
- and is work-based <u>training</u> enough?

NTEC

- ***N**uclear **T**echnology <u>**E**ducation</u> **C**onsortium*
- Established following consultations with the UK nuclear sector (industry, regulators, MoD, NDA, Government Departments, Cogent, etc)
- Universities of Birmingham, Central Lancashire, City, Lancaster, Leeds, Liverpool, Manchester and Sheffield, Imperial College London, the UHI Millennium Institute & the Nuclear Department, Defence Academy of the United Kingdom

NTEC

- Modular programme (core + options)
- Full-time (1 year), part-time (3 year) or via distance learning
- Postgraduate certificate/diploma or MSc degree in Nuclear Science & Technology
- Modules available individually for CPD
- www.ntec.ac.uk
- Option module N13 – Criticality Safety Management

N13

- One week module attended by a mixture of EPSRC funded ‘full-time’ students and fee-paying CPD students from industry (including AMEC, BABCOCK, BAE, MAGNOX, Rolls-Royce and SERCO)
- Roughly a 50:50 split
- Numbers growing year-on-year…
- Distance learning students from the IAEA, from Canada, and elsewhere…

N13

- Syllabus includes:
  - Review of previous criticality incidents and accidents
  - Criticality assessment methods (i.e. hand calculation methods, subcritical limit graphs)
  - An introduction to MONK
  - Criticality prevention and monitoring methods
  - Criticality event consequences, etc
- Biased towards UK-centric standards and guidance

N13

- As criticality safety is a practically focused subject, it does not lend itself well to formal assessment through examinations
- N13 assessed by coursework only
- Assignments designed to mimic the type of work performed by a professional criticality analysts
- *i.e.* to test a students understanding, and ability to apply criticality safety methods, students are required to produce a 'complete' criticality safety evaluation of a hypothetical facility

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NNPP-specific training

- The Defence Academy also offers a similar module to Masters level students from the UK Naval Nuclear Propulsion Programme (NNPP)
- Students include experienced Royal Navy submarine PWR operators and civilian project managers, as well as health physicists from both services
- The MSc in Nuclear Technology and Safety Management gives students the opportunity to further develop their criticality safety expertise during the 20 week project phase of their course

MSc Design Study

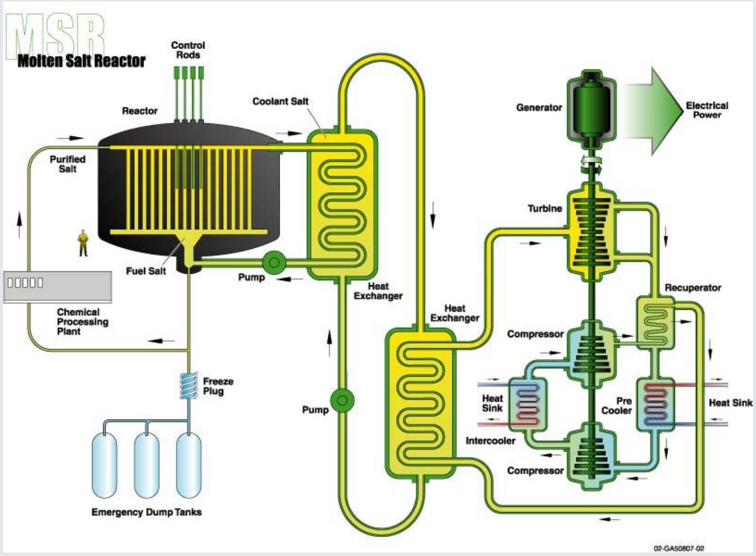
- 4-8 students form a design team with the explicit task to design or adapt a reactor plant capable of providing propulsive power to a ship of specified size/capability
- Effectively a feasibility study, the most recent design team project was the navalisation of a molten salt reactor (NMSR) for use in a 5000-tonne attack submarine

URD & SRD Requirements

- 40 year operational life
- Maximise time between refuelling
- Fitment into a relatively small ‘Upholder Class’ submarine
- Maximum speed not below 30kts
- Quiet in operation
- Safe through life

HMCS Windsor (ex HMS Unicorn)

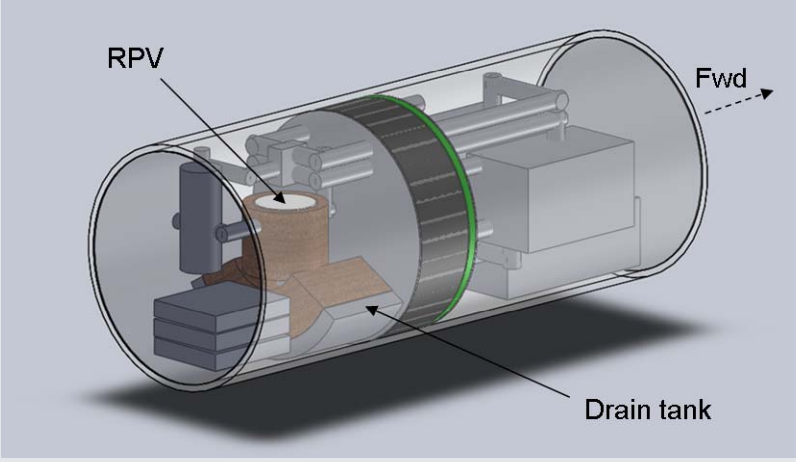
MSR Schematic



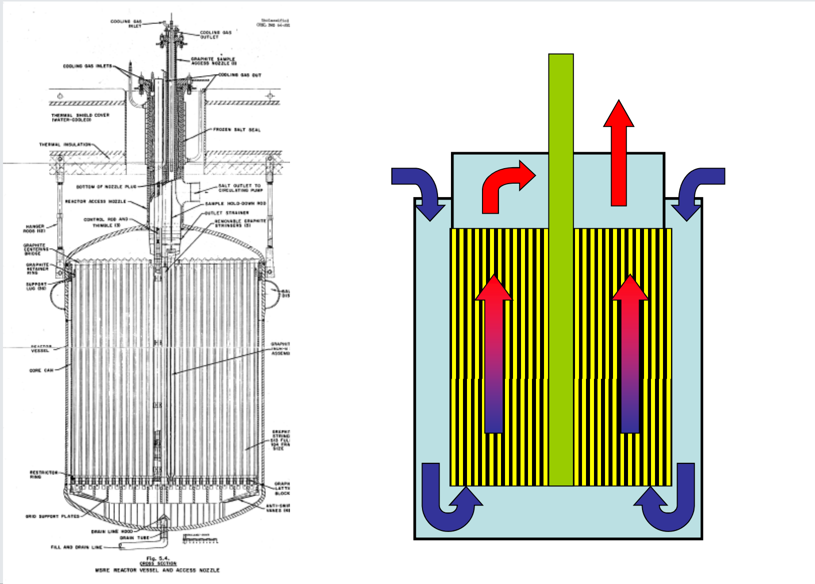
MSR Features and Benefits

- Benefits
  - Very power dense
  - Low pressure operation
- Features
  - Significantly higher temperatures
  - **Fissile material not fixed**
- Must ensure that the design of the primary circuit only allows criticality to occur under controlled conditions within the core region

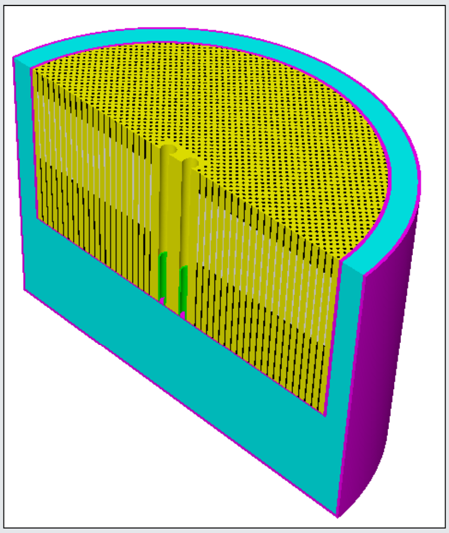
Reactor Compartment



Molten Salt Reactor Experiment

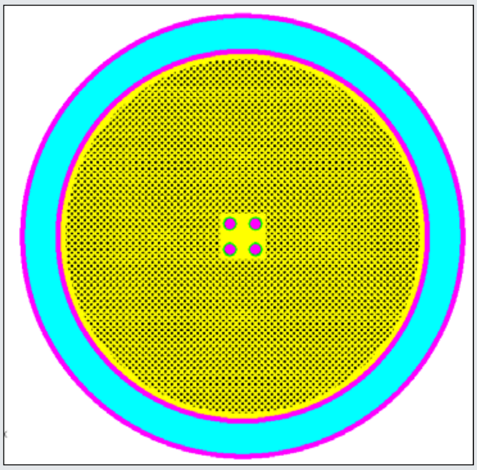


MSRE Models



- Fuel channels approximated to circular
- Equal amounts of resonance and thermal fission
- More reactive
- Better moderation

Modifications for NMSR



- Smaller core
- Smaller fuel channels
- More fuel channels
- Reflector

MSRE Fuel Drain Tank

- MSRE vessel
  - Parameters
    - Cylindrical
    - 1.27m diameter, 2.18m high
    - Volume 2.27m^3
    - Hastelloy-N
    - 32 cooling tubes, 4.8cm diameter
    - Electrically heated

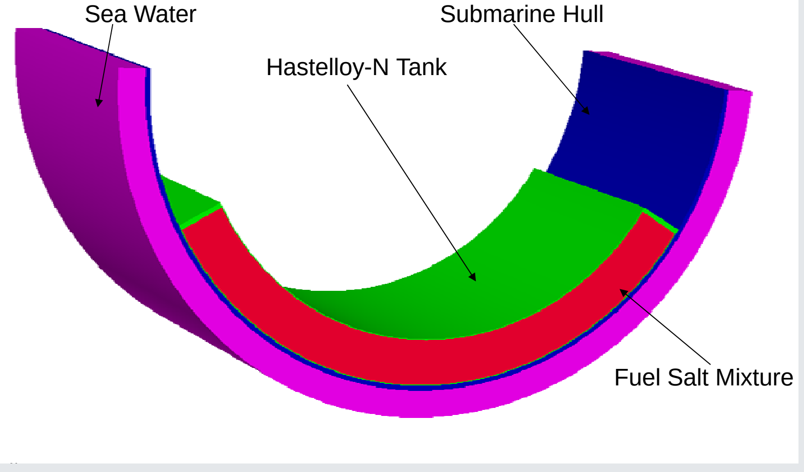
NMSR Fuel Drain Tank

- NMSR fuel drain tank required to hold primary circuit volume, 8.04 m^3
- Requires passive heat removal system
- Size constrained by limitations posed by the submarine
- Must conform to appropriate standards
- Must be justifiable for operation in the UK, i.e. acceptable by the Defence Nuclear Safety Regulator (DNSR)

NMSR Fuel Drain Tank

- To optimise use of space a U-shaped drain tank was designed to fit against the inside of the submarine hull
- Advantage of this approach was the provision of passive decay heat removal by conduction through the hull
- The essentially flat tank was initially considered a rectangular parallelepiped of depth 0.5 m, and a length and breadth of 2.8 × 7.0 m, respectively

NMSR Fuel Salt Drain Tank



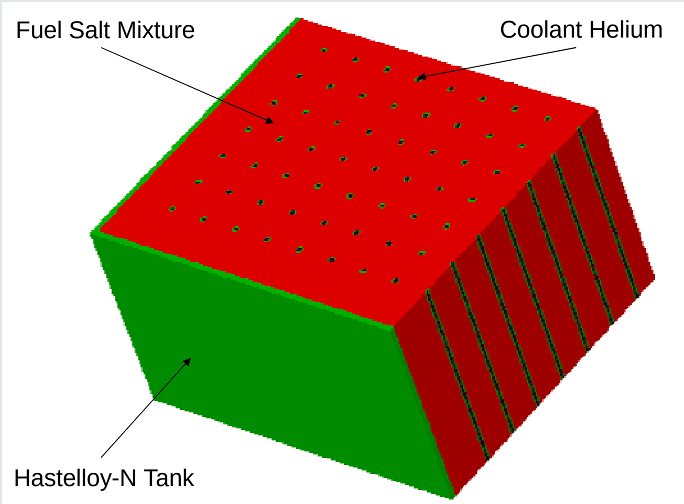
NMSR Fuel Drain Tank

- Hand calculations indicated that this would be subcritical (k_{eff} = 0.441) when fully filled; a fact confirmed by subsequent MONK simulations of the accurate geometry (k_{eff} = 0.446)
- MONK analysis also took account of the moderating effects of seawater and showed that if, simultaneously, the uranium concentration was doubled whilst the inside of the submarine was flooded, the fuel in the drain tank would still remain subcritical (k_{eff} = 0.792)

NMSR Salt Fuel Drain Tank

Model	Fuel Concentration	Reflector	K_{eff}
Hand Calculations	Normal	None	0.441
MONK Model	Normal	None	0.4349
MONK Model	Normal	Outer	0.4459
MONK Model	Normal	Outer and Inner	0.5618
MONK Model	Double	None	0.7198
MONK Model	Double	Outer	0.7325
MONK Model	Double	Outer and Inner	0.7919

NMSR Heat Exchanger



Design Study Conclusions

- Students successfully showed that design of a passively safe system is feasible
- Primary circuit components, apart from the core region, should not achieve a critical mass of fuel salt under foreseeable <u>operating</u> conditions
- Only scratched the surface (i.e. filling accidents, or LOCA, were not considered)
- Further work is underway (Physor 2012)

Conclusions

- Postgraduate education in criticality safety can provide students with the necessary skills and knowledge to enable them to solve realistic criticality safety problems
- Writing detailed criticality assessments from the outset allows them to demonstrate many skills learnt by trainee criticality engineers in industry

Conclusions

- If developed into a postgraduate certificate the module could form a suitable starting point for graduate entrants to the field
- As our main role is to support the NNPP through research and consultancy (as well as training all UK submarine operators), we are outside of the UK WPC, so to improve our modules we would welcome input from practising criticality analysts

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Acknowledgements

- Reactor Physics - Mr Tom Grime
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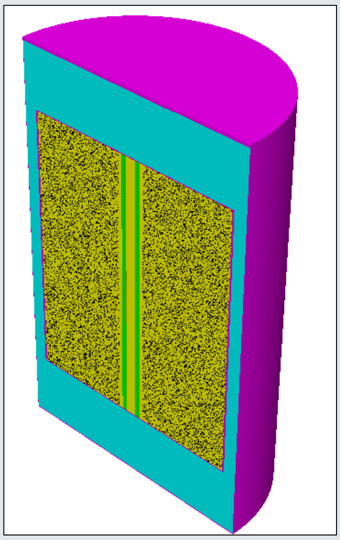
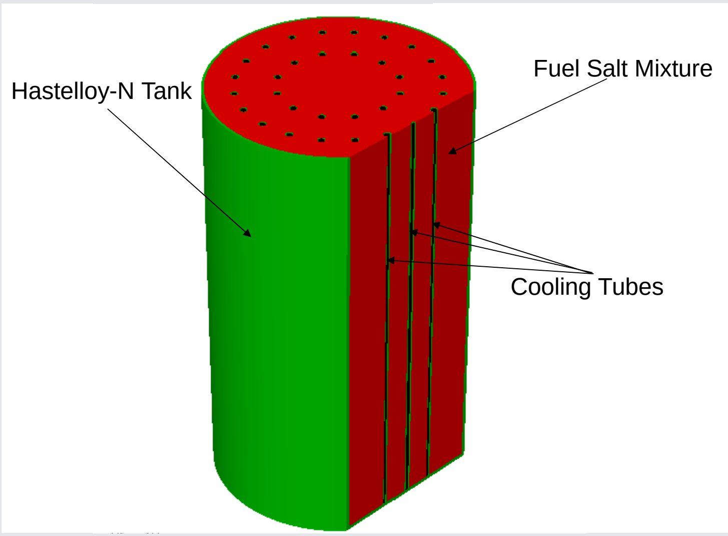
- Reactor Dynamics - Mr Simon de Haas
- Shielding - LV Edouard Jonnet
- Chemistry & Materials - Mr Michael Connolly
- Safety - Lt James Law RN
- Navalisation & Refuelling - Mr Peter Wort

MSRE Models



- Homogeneous model
- No fuel channels
- Less critical
- Smaller mean free path
- Lots of resonance capture

MSRE Fuel Salt Drain Tank



MSRE Fuel Drain Tank

- Oak Ridge analysis assumed:
  - Fuel Salt at 20°C
  - Surrounded by a water jacket
- However following data not specified in released documents
  - Density (since mixture is solid at 20°C)
  - Spacing of cooling tubes
  - How the cooling tubes were modelled

MSRE Fuel Salt Drain Tank

Comparison of results from MONK simulation and hand calculations

Method	**Reflected**	**K_{eff}**
Hand	No	0.6634
MONK	No	0.8898
MONK	Yes	0.9375
MSRE Data	Yes	0.7740

Filling Accident Scenario

- MSRE scenario
  - Partial Fuel Salt freezing leading to high fuel concentration
  - No operator intervention
  - Pressure control system for regulating core filling rate has failed
  - Initial operating power 1W

Filling Accident Scenario

- For MSRE it was postulated that:
  - Criticality was achieved before core region was full
  - Power quickly increased to the 15MW scram setting
  - Only two of the three control rods were inserted
  - Maximum power spike of 24MW
  - Core continued to be filled
  - Restart occurs
  - Power rises