Nuclear Innovation Programme – Thermal Hydraulics

Richard Underhill, Principal Consultant

IoP Conference – 22 October 2019

FNC 60148/113413V

SYSTEMS AND ENGINEERING TECHNOLOGY

FRAZER-NASH CONSULTANCY

Introduction

Thermal hydraulics underpins the performance and safety of all SMR and AMR technologies

Improved thermal hydraulics modelling is essential to enhance designs and improve safety

Increased confidence in thermal hydraulic modelling tools and understanding will lead to:

- Reduced costs
- Better efficiency
- Simpler designs

Opportunity for the UK to be an international leader in thermal hydraulics

- Supporting the UK Nuclear Sector Deal
- Phase 1 achievements and value
- Phase 2 plan and expected benefits
- Application to advanced nuclear technologies

Digital Reactor Design: Nuclear Thermal Hydraulics

Our vision is to create an enduring, co-ordinated and industry focused nuclear thermal hydraulic capability in the UK

- Phase 1 project (2017 to 2019) delivered three key objectives:
  - Specification of a new thermal hydraulics facility
  - Specification of thermal hydraulic model development
  - Initial innovative model development
- Phase 2 project (2019 to 2021) will focus on **industrial application and commercialisation:**
  - Heat transfer and natural convection
  - Predictive capability for passive safety arguments
  - Upskill UK in modern digital methods
  - Relevant to all SMR and AMR technologies

Nuclear Thermal Hydraulics: Supporting the UK Nuclear Sector Deal

Establish **world leading** UK capability in thermal hydraulics for **passive safety systems**, become preferred partner engaged in collaborative design projects for new reactors and **reduce the cost** of nuclear reactor design and build

Improved design

Enhance designs and create step change in delivery of nuclear design programmes.

Digital design process

Increase uptake of modern digital engineering practices within the UK nuclear industry.

Better efficiency

Improve understanding and safety of through life performance of reactor components.

Passive safety designs

Improve UK predictive modelling capability and understanding of passive safety arguments.

Upskill UK workforce

Develop a highly-skilled workforce to drive design improvements and underpin future operation.

International collaboration

Increase UK participation and collaboration in international activities.

Nuclear Thermal Hydraulics: Phase 1

Phase 1 has now finished. This section summarises what has been achieved during the project and the value that has been delivered

Phase 1: Our Team

- Phase 1 project had three key objectives:
  - Specification of a new thermal hydraulics facility
  - Specification of thermal hydraulic model development
  - Initial innovative model development

Phase 1 Team

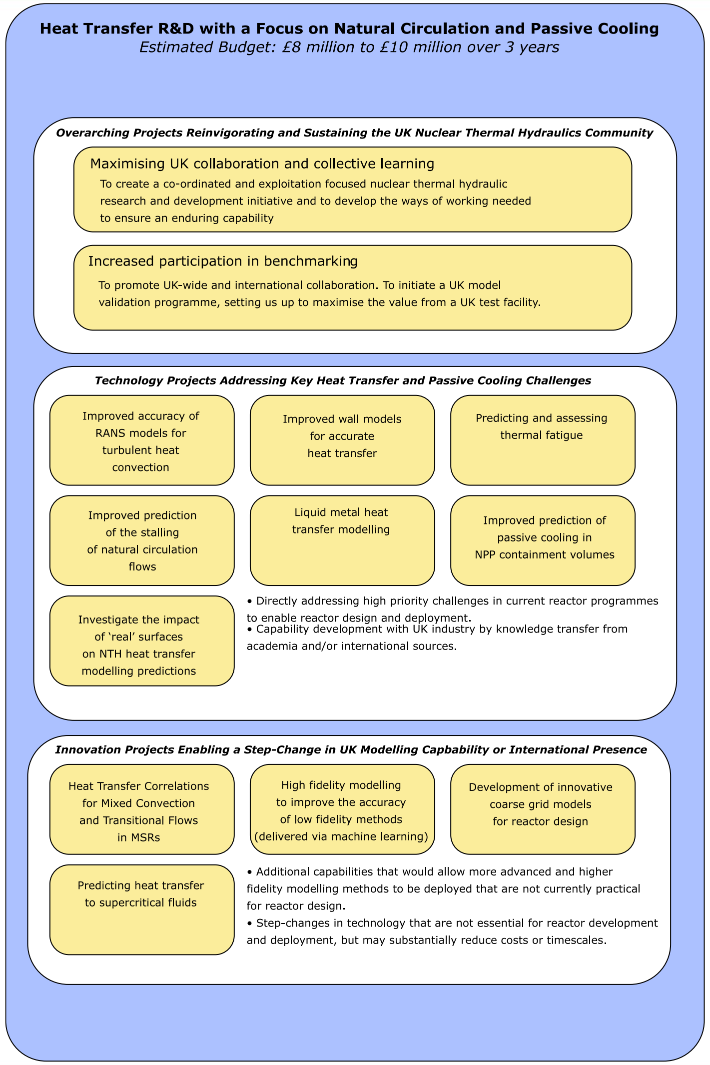
Phase 1 Thermal Hydraulics Facility: Achievements

- Reviewed thermal hydraulic test facilities worldwide
- Captured user requirements for the facility
- Developed test facility specification that is:
  - Flexible, bounding and able to accommodate all SMR and AMR technologies
- Assessed Menai Science Park site against specification
- Developed commercial opportunities plan with vision for facility
- Investigated benefit to other Nuclear Innovation Programme projects
- Made clear recommendations for test facility to maximise value and appeal of the test facility
- UKAEA is now leading the design and build program for the test facility and has submitted a business case to BEIS for approval

Image courtesy of M-SParc

Phase 1 Model Development: Achievements

- Reviewed current state-of-the-art in thermal hydraulic prediction
- Captured user requirements for model development
- Specification for thermal hydraulic model development
  - Brought together UK thermal hydraulics community in workshop
  - 34 research and development proposals identified
  - Grouped into reactor and modelling technology programmes
- Initial innovative model development:
  - Single phase: Natural convection loops
  - Liquid metal: Cover gas aerosol dynamics and hot plenum region
  - Smart component models: Sub-Channel CFD (SubChCFD)
- Regular meetings now being held through Nuclear Thermal Hydraulics (NTH) Special Interest Group (SIG)



Nuclear Thermal Hydraulics: Phase 2

Phase 2 is now underway. This section summarises the plan for the project and the benefits that will be delivered as a result.

Phase 2: Our Team

- Phase 2 project (2019 to 2021) will focus on **industrial application and commercialisation:**
  - Heat transfer and natural convection
  - Predictive capability for passive safety arguments
  - Upskill UK in modern digital methods
  - Relevant to all SMR and AMR technologies

Phase 1 Team - Building Knowledge Base

Frazer-Nash Consultancy; The University of Manchester; EDF Energy; The University of Sheffield; Westinghouse; Science & Technology Facilities Council

Additional Partners - Upskilling Wider Industry and Routes to Exploitation

U-Battery Local Modular Energy; DBD; LeadCold; Terrestrial Energy; Rolls-Royce; National Nuclear Laboratory; Moltex Energy (safer, cheaper, cleaner); Checkendon Hill

Independent Expert Advisory Peer Review Group

(Individuals from various Organisations)

Phase 2: Plan

Phase 2: Provide predictive modelling capability for passive safety arguments for **SMRs and AMRs** (water, gas, molten salt and liquid metal) through innovation, development and commercialisation

6 Technical Volumes
Description of good practice for industry and regulators.

4 Case Studies
Demonstrate use of Technical Volumes to real SMR and AMR industrial applications.

Integration
Ensure thermal hydraulics project is integrated with Virtual Engineering program and test facility.

Focused R&D
Address gaps in knowledge and support case studies.

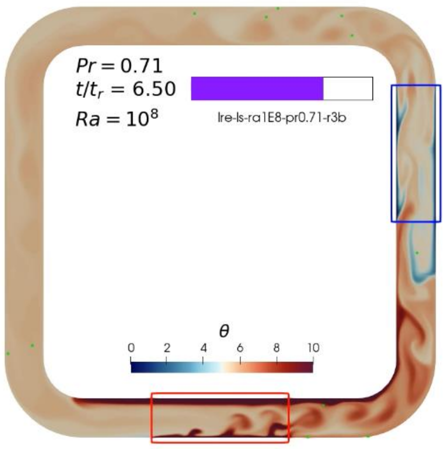
Dissemination
Disseminate research to UK community through NTH SIG and wider Nuclear Innovation Programme.

International engagement
Support international engagement and participate in next NEA CFD benchmark.

Phase 2: Focused R&D - Natural Circulation and Passive Cooling

University of Manchester

- Objective: Develop best practice and approach for modelling natural circulation loops
- Review historical analyses and tests to identify suitable existing experimental loop
  - With both stable and unstable behaviour
- Solve case with a 1D system code
  - Compare with experiment and identify limits
- Solve case with a CFD code
  - Investigate sensitivity to mesh size, turbulence modelling and other parameters
  - Compare with experiment and 1D results



Complex transient behaviour in a natural convection loop

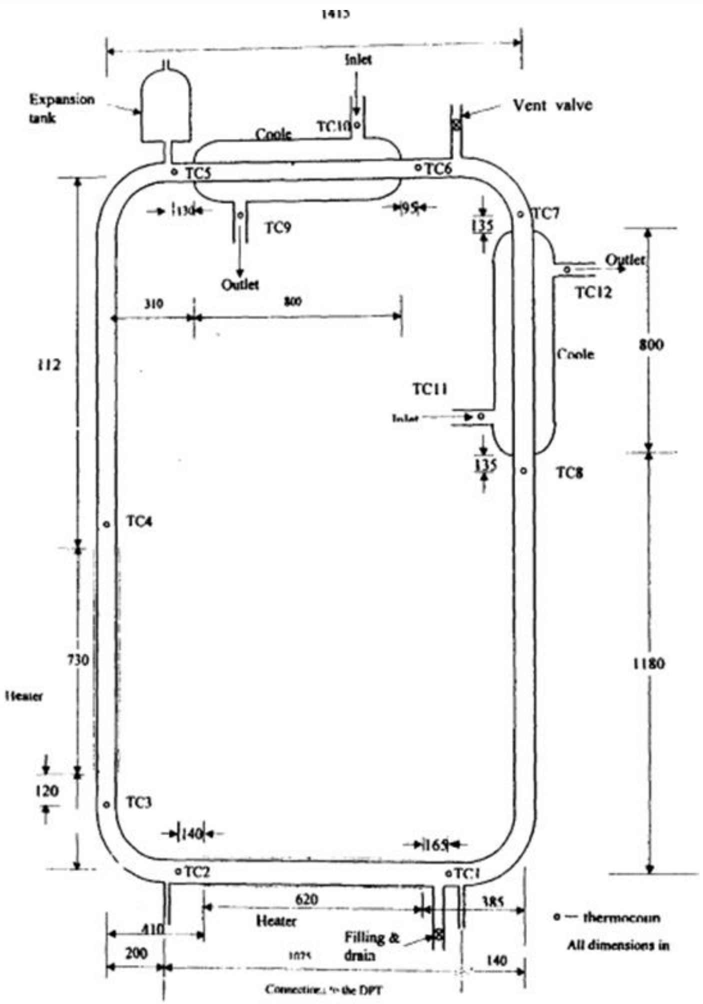
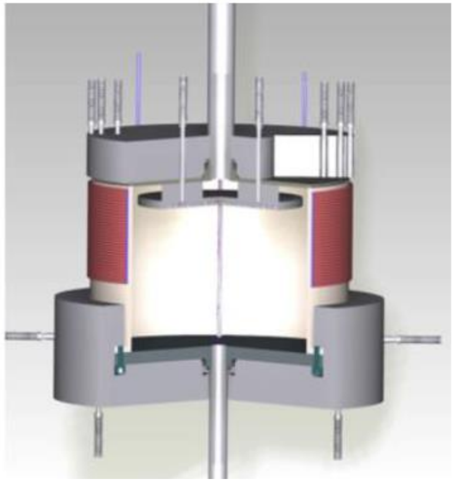


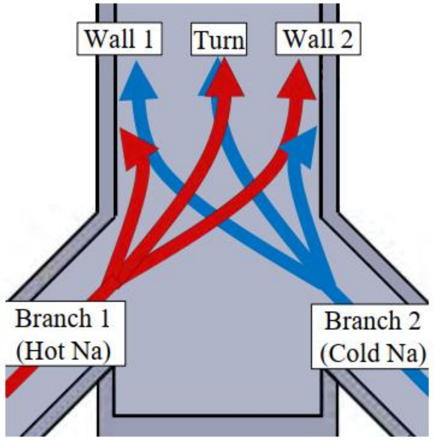
Fig.1a: Schematic of the test

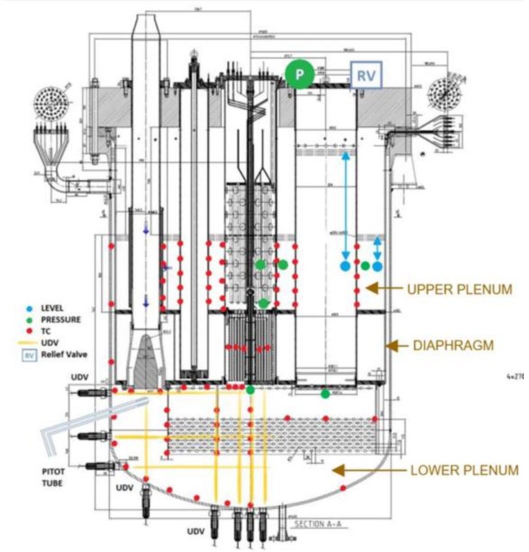
Phase 2: Focused R&D - Liquid metal heat transfer modelling

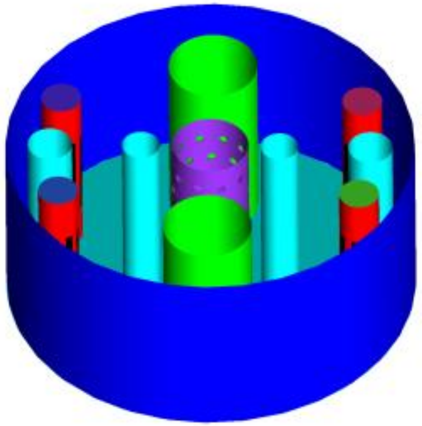
University of Sheffield

- Objective: Develop best practice and physical understanding of combined phenomena of liquid metal e.g.
  - Impinging jet, stratification, jet mixing, thermal striping
- Task 1 - High-fidelity study of the 3D test section of TALL-3D facility and an assessment of RANS models
- Task 2 - RANS study of thermal striping at a Y-junction and a T-junction of non-isothermal sodium validated against experimental data
- Task 3 - High-fidelity simulation of the hot plenum of E-SCAPE with well-defined boundary conditions





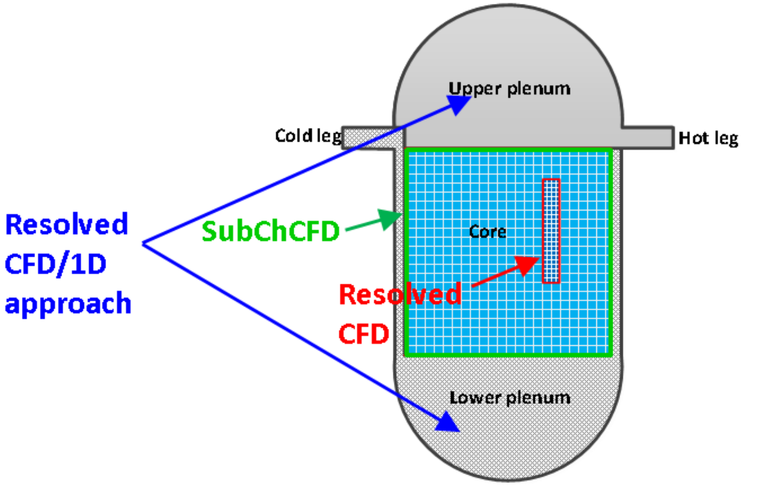


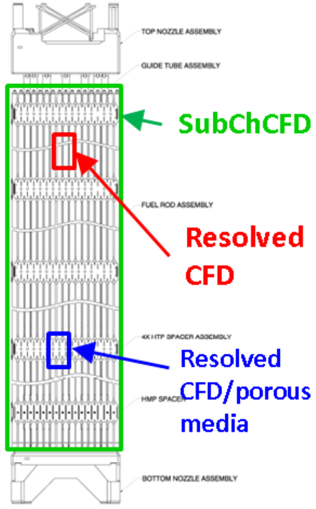


Phase 2: Focused R&D - Coarse grid CFD Coupling (SubChCFD)

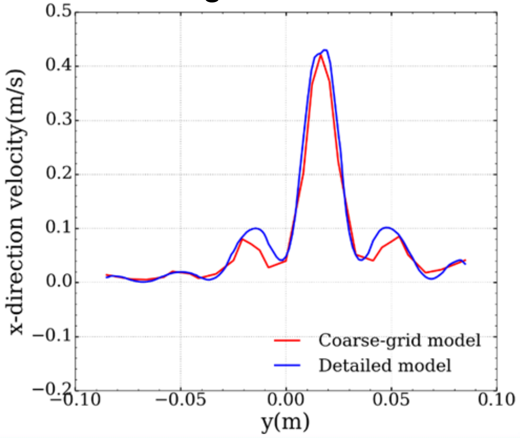
University of Sheffield

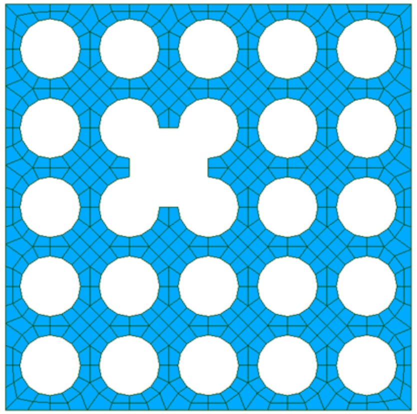
- Vision: To develop a modern CFD-based ‘sub-channel’ framework for Nuclear Power Plants
- Advantages: Significant reduction in computing cost with respect to conventional CFD; Ease of coupling with resolved CFD and/or porous media approach
- Baseline model has been developed and validated against a number of 2D and 3D test cases.
- Benefits: This could be applied to any reactor technology, and could allow whole reactor core to be modelled in CFD with ability to embed detailed CFD models in specific areas - Mesh size reduced by 150 times.
- Potential to bridge gap between empirical/data driven models to modern best practice and beyond





Fuel bundle with blockage
Coarse grid 0.14M cells, detailed 21M cells





Phase 2: Industrially relevant case studies

SMR Case Study

Light Water Natural Convection relevant to an SMR.

LMFR Case Study

Passive Decay Heat Removal in a LFR.

MSR Case Study

Development of Heat Transfer Correlations in a Molten Salt Reactor with Uncertainty Quantification.

HTGR Case Study

Whole Core HTGR Model.

Phase 2: Target Benefits

- Set of Technical Volumes and Case Studies to upskill UK
- Thermal hydraulic tools integrated into Virtual Engineering toolset
- Passive safety understanding and best practice that can be applied to future reactor development
- Advanced modelling techniques to improve designs and enhance efficiency for SMR and AMR designs
- Closer links with SMR and AMR developers and increase international collaboration
- Engagement with GenIV International Forum and US National Labs on NEAMS

The Big Picture

4.6 million
Delivering new unique capability for UK export.

8 reactor developers
Solving specific challenges for advanced nuclear technologies

4 years
A long-term project enabling the establishment of an enduring capability

2 collaborations
This work has directly led to Frazer-Nash involvement with international reactor developers to support their design.

40 engineers
Upskilling UK workforce across industry and academia in new reactor technologies with wider dissemination to UK community.

International Influence
Enabled the participation in a multitude of international programmes.

Summary

Thermal hydraulics underpins the performance and safety of all SMR and AMR technologies

Phase 1: Model development and facility specification with initial innovative new methods

Phase 2: Developing advanced modelling practices for SMR and AMR technologies

Increased confidence in thermal hydraulic modelling tools and understanding will lead to:

- Reduced costs
- Better efficiency
- Simpler designs

- Thermal hydraulics is key to meeting cost reduction target
- Project focused on industrial applications for SMR and AMR developers
- Upskilling UK workforce and disseminating knowledge to UK community
- Providing route to international collaboration and commercialisation

Don’t want to ask your question now? Come and find out more about our research and how you can be involved at Stand 11, in the exhibition room.

www.innovationfornuclear.co.uk

Thermal hydraulics

Securing skills and developing models through Nuclear Thermal Hydraulics research and innovation in the UK for SMR and AMR technologies.

Advanced Manufacturing and Materials

Developing understanding in advanced joining techniques for nuclear applications. Helping to unlock the blockers for the adoption of new technologies in nuclear new build

Safety & Security

Researching new techniques and methods that provide engineers with a greater insight into their reactor technology’s safety and security performance, empowering them to make risk informed decisions that drive cost reduction.