9–10 November 2023 • Imperial College London

Nuclear Institute

NUCLEAR MODELLING 2023

6th Annual Modelling in Nuclear Science and Engineering Seminar

ABSTRACTS

Room G41, Department of Earth Science and Engineering, Royal School of Mines, Imperial College London, Prince Consort Road, London SW7 2BP

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WELCOME

The 6th Modelling in Nuclear Science and Engineering Seminar is to bring together the nuclear community to share innovative and different ways of adopting modelling to help improve design and protect the society by improving of safety of plants.

The aim of scientific modelling as an activity is to make features and performance of the design easier to understand, quantify, visualise, or simulate by referencing it to existing and usually commonly accepted knowledge, and is applied across all kinds of industries and walks of life. The Seminar this year offers a fantastic line-up and a fascinating set of topics and themes to offer scientist and engineers a view on future developments.

The Seminar aims to provide practical advice, information sharing and a discussion platform to facilitate and improve understanding, problem-solving and cooperation. Massive leaps and scale of opportunities by the introduction of digital technologies have presented the nuclear modelling community with tools that were inaccessible 2 decades ago, and whilst the UK nuclear sector alone still expects significant near to mid-term investment, the opportunities for ongoing research across the whole nuclear lifecycle continue to present themselves.

Professor Ali Tehrani, CEng, FNucl, FIMechE

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DAY 1 THURSDAY 9 NOVEMBER

SESSION 1: IMPACT OF MODELLING IN NUCLEAR ENGINEERING AND SCIENCE

10:00 **Keynote**

Future prospects of AI in nuclear engineering modelling

***Christopher Pain**, **Ali Tehrani**, **Claire Heaney**, **Boyang Chen**, **Toby Phillips**, **Linfeng Li**, **Jiansheng Xiang**, **Steven Dargaville**, **Omar Matar**, **Paul Smith** and **Andrew Buchan**,*
Imperial College London

10:30

Integrated modelling approaches for SMR core design

***Oliver Hannant**[*1], **Tom Wright**[1], **Ben Cooper**[1], **Christopher Bennett**[1]*

[1] Rolls-Royce SMR
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Abstract

The Rolls-Royce SMR has been developed to provide clean, affordable energy to help decarbonise all aspects of the energy market. The SMR design has been developed from scratch which has allowed commonly held assumptions to be challenged in an attempt to minimise cost, layout size and build time, whilst optimising the cost of energy produced and the total environmental impact of the plant.

These assumptions can only be challenged through the application of robust and detailed modelling of the whole power station, from the engineering design through to commercial and economic models. In particular, detailed modelling of multiple core design iterations has allowed confidence that standard fuel lengths and reactivity control mechanisms can be changed allowing for a holistic benefit to the entire power station design.

This presentation will provide an overview of the range of modelling applications which are conducted to inform the design and safety justification of the Rolls-Royce SMR reactor core and plant. These disciplines include reactor physics, sub-channel thermal hydraulics, criticality, fuel performance, plant systems, CFD and radiation shielding. Importantly the links between these disciplines will be highlighted which provides insight into how more advanced and integrated modelling capabilities can help improve plant design; from the simplification of systems, potential uprates in output or the improvement in performance margin.

Aspirations for future modelling efforts will also be presented based on a reactor plant and core design perspective. Shortfalls in the analytical approaches to design still exist; however, advances in computing power and the application of AI makes these challenges eminently achievable in the near future.

Keywords

SMR, reactor physics, thermal hydraulics, criticality, fuel performance, CFD

DAY 1 THURSDAY 9 NOVEMBER

10:50

Embracing empirical modelling methods in the journey of impactful mechanistic model development

Eleftherios Vlazakis*[*1], **Caroline Pyke** *Author*[2]

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[2] Decision Science, National Nuclear Laboratory Ltd, Sellafield, UK
[*] Corresponding author email: **eleftherios.vlazakis@uknnl.com**

Abstract

Model insights require model understanding. However, as the number of parameters in a mechanistic model increases beyond 5, 10, or 50, it is impossible to keep track of each effect and appreciate the interactions. To understand the parameter effect on the outcome requires the strengths of empirical modelling. By embarking on a journey of empirical/semi-empirical modelling methods, better, insightful and generalisable mechanistic models can be developed.

i. This starts with global, as opposed to local, Sensitivity Analysis (SA) which provides at least a qualitative indication (factor screening) about the parameters main and interaction effects.

ii. Working within resource limitations a more detailed SA can provide quantitative evaluation to allow for factor prioritization, as well.

iii. Following this, the most influential parameters can be used to build a surrogate model to replicate the predictions of the mechanistic model in significantly sorter time.

iv. Then, observed data helps to estimate parameter values that are relevant for the application by performing model calibration. Experimenting by using one-factor-at-a-time must not be the answer. Instead, methodological model calibration is required which can overcome the noise and bias to inverse predict values that satisfy the observed data.

v. Finally, in embracing the empirical modelling methods, uncertainty in the predictions of the mechanistic model can be incorporated. The outcome is a model that can generalise and resemble real experiments.

As these tasks require skills from multiple fields this talk will review how empirical and mechanistic modellers can work together to create insightful and generalisable models.

Keywords

Sensitivity Analysis, Model Calibration, Uncertainty Quantification, Semi-empirical Modelling, Surrogate modelling

DAY 1 THURSDAY 9 NOVEMBER

SESSION 2: MULTI-PHYSICS AND MULTI-SCALE MODELLING

Chair: ***Prof. Paul Smith***

11:20 Keynote
IAEA Efforts to Support Member States to Assess and Enhance the Safety of Current and Future Nuclear Installations

Ana Gomez Cobo[1]

[1]Head of Safety Assessment, International Atomic Energy Agency
Author e-mail **A.Gomez-Cobo@iaea.org**

Abstract

The presentation will describe the work of the International Atomic Energy Agency in two major areas, these being design safety and safety assessment of existing, evolutionary and innovative power reactors. It will cover the work being done on relevant safety standards and other publications, capacity building among the Member States, and the Technical Safety Review services. It will also summarise key work for the next biennium 2024-25. Finally, it will provide a brief update on IAEA's Nuclear Harmonisation and Standardisation Initiative (NHSI).

11:50 Modelling and Simulation: Fostering international co-operation within the OECD NEA Working Party on scientific issues and uncertainty analysis of Reactor Systems (WPRS)

Kostadin Ivanov[*1], Hakim Ferroukhi[2], Michelle Bales[3], Oliver Buss[*3], Ian Hill[3], Tatiana Ivanova[3]

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Abstract

Under the guidance of the Nuclear Science Committee of the OECD Nuclear Energy Agency (NEA), the Working Party on Scientific Issues and Uncertainty Analysis of Reactor Systems (WPRS) deals with reactor physics, radiation transport and dosimetry, core thermal-hydraulics (T/H), fuel performance, and associated multiphysics aspects for present and future nuclear power systems. It studies the modelling and simulation (M&S) of reactor systems, along with verification, validation and uncertainty quantification. It acts as a platform for international collaboration sustaining a vibrant community of practice, fostering periodic and synergistic interactions among its participants. Main foci of the WPRS activities are recommendations and policy advice in its domain of expertise, international benchmarking activities, data preservation, and education.

The WPRS runs 12 active benchmarks covering a wide variety of systems ranging from conventional reactor systems to advanced reactor designs, including micro- and small modular reactors (SMRs). Most recently, two notable new activities have been started: a multi-stage T/H code validation benchmark based on data measured at the High Temperature Test Facility (HTTF) at Oregon State University, US, and a Task Force on Artificial Intelligence and Machine Learning (AI/ML) for Scientific Computing in Nuclear Engineering, which will evaluate the performance of AI/ML in multiphysics M&S of reactor systems.

In the domain of data preservation WPRS is overseeing four database projects including the well-known International Handbook of Evaluated Reactor Physics Benchmark Experiments (IRPhE) Project with 169 different experimental series that were performed at 57 different nuclear facilities. Another significant project is the Shielding Integral Benchmark Archive and Database (SINBAD), which is pioneering the implementation of open source software methodologies into the benchmark database development.

On the education side, WPRS has successfully organised the first International School on Simulation of Nuclear Reactor Systems (SINUS) this year. It delivered a hybrid, hands-on-training encompassing multiphysics simulations and associated uncertainty quantification methodologies.

The presentation will aim at providing an overview of the WPRS activities emphasising the diverse collaboration opportunities.

Keywords

International Co-operation, Multiphysics, Reactor Physics, Benchmarks, Uncertainty Analysis

12:10 Computation of multi-physical interfacial Newtonian, two-phase dusty (Saffman) and non-Newtonian Eringen micropolar transport in nuclear reactor ducts with a modified Differential Quadrature Method (DQM)

***O. Anwar Bég**[*1], **R. K. Chandrawat**[2], **V. Joshi**[2], and **S. Kuharat**[1]*

[1] Multi-Physical Engineering Sciences Group (MPESG), School of Science, Engineering, and Environment (SEE), University of Salford, Manchester, UK
[2] Fluid Dynamics Group, Department of Mathematics, LP University, Jalandhar, India
[*] Corresponding author email: **O.A.Beg@salford.ac.uk**

Abstract

In this work, we will describe recent progress in using B-Splines in the differential quadrature method (DQM) for simulating two-dimensional periodic transport in a nuclear duct. Unsteady flow of two immiscible (either Newtonian or dusty and micro-polar fluids) with a stable and moving interface will be addressed. Numerical solutions for linear velocity, particle velocity, Eringen micro-rotation (angular velocity) are presented. Both fluids are considered to flow under three different pressure gradients-constant, decaying and periodic pressure gradient and the flow characteristics are scrutinized for each case. The effects of the key hydrodynamic and solutal parameters i.e., Reynolds number, particle concentration parameter, Eringen micropolar material parameter, volume fraction parameter, pressure gradient, time, viscosity ratio and density ratio on transport characteristics are given. Furthermore some further simulations to include magnetohydrodynamic (MHD) effects and full visualization of the interface evolution are provided. DQM is shown to be a good alternative to existing commercial software platforms which can be programmed easily in MATLAB and achieves very fast convergence and compilation times.

Keywords

B-Splines, Differential Quadrature Method (DQM), Micro-Polar Fluids, magnetohydrodynamic (MHD), nuclear duct

DAY 1 THURSDAY 9 NOVEMBER

12:30 ## SHOWBIZ: A multi-physics 3D code to simulate a fuel rod cladding embrittlement in normal reactor operation, transport and storage and during LOCA and RIA transients

M. Guémas[1], C. Leclere[1], M. Salvo[1], T. Taurines[1], A. Del Masto*[1]

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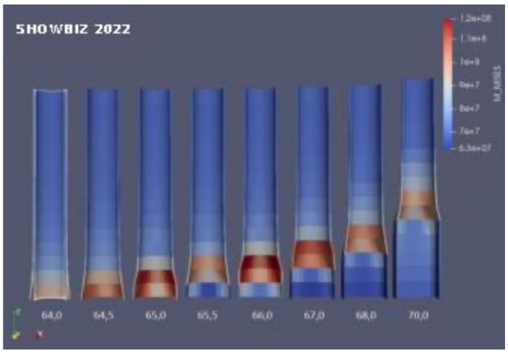
Abstract

Light water reactor safety is directly linked to the performances of the first barrier. The ability to predict the behaviour of fuel rod cladding in multiple scenarios is therefore crucial, but challenging, due to the coupling of multiphysical phenomena involved in each situation.

The 3D software SHOWBIZ (Studying Hydrogen and Oxygen Weakening Behavior In Zirconium) developed by IRSN is dedicated to the modelling of a single fuel rod cladding throughout its life cycle, i.e. in the reactor, in transport and storage situations. Possible incidents or accidents are taken into account like Loss Of Coolant Accidents (LOCA) or Reactivity-Initiated Accidents (RIA).

SHOWBIZ is based on the finite element method, here used to simulate the thermomechanical behaviour of the cladding (thermal expansion, diffusion, creep, rupture), along with chemical phenomena most likely to degrade its integrity, such as oxidation and hydriding of the cladding outer surface. SHOWBIZ is also able to simulate the internal environment of the cladding and the chemical interaction of gaseous species in the channel between the fuel pellets and the inner surface of the cladding. This last feature allows in particular to study the secondary hydriding that occurs in defective fuel rods due to the entry of water.

The implemented models are validated though a number of experimental investigations aiming to reproduce nominal and accidental scenarios.



Keywords

SHOWBIZ, modelling, LOCA, RIA, transport & storage

DAY 1 THURSDAY 9 NOVEMBER

SESSION 3: AI, INNOVATION AND RECENT DEVELOPMENTS IN REACTOR PERFORMANCE AND SAFETY MODELLING

14:00 **Keynote**

Great British Nuclear Update

Mike Roberts, *Head of Technical Delivery, Great British Nuclear*

14:30

Technology development for the deployment of high temperature reactors for alternate generation of electrical energy and hydrogen

***Mark Bankhead**[*1], **Jorge Wier**[2], **Christopher Connoly**[3] and **Kate Taylor**[3]*

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[2] Reactor Physics, National Nuclear Laboratory, Preston, UK
[3] Chemical and process modelling, National Nuclear Laboratory, Sellafield, UK
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Abstract

Separately the UK government has awarded funding exceeding £35m to two consortia. The first is led by Japan Atomic Energy Agency & National Nuclear laboratory and the second by Ultrasafe Nuclear & Jacobs. Both consortia are pursuing designs for a UK high temperature gas reactor and the specialist advanced fuel it requires - coated particle fuel. These reactors promise to deliver safe and sustainable nuclear energy, utilising technology that is both proliferation resistant and passive safe providing more flexible options for deployment. Simultaneously these reactors deliver much higher outlet temperatures than existing technology, allowing the heat to be used directly to decarbonise industrial processes. At scale these reactors will enable the large-scale production of hydrogen, providing a sustainable source of this vital energy vector.

In this paper we will present an overview of the operational challenges for the deployment of HTGR for alternate generation of electricity and hydrogen at scale. We will look at the technical challenges ahead including the need to establish market driven design optimisation goals, established through system level modelling of potential deployment scenarios. We will update generally on the role of modelling and simulation and digital twins to solve some of the deployment challenges, including exploring the role of AI in control and optimisation of reactor design.

Keywords

HTGR, hydrogen, nuclear

DAY 1 THURSDAY 9 NOVEMBER

14:50
GMIT: An automation tool for post-closure criticality safety assessments

***Jiejie Wu**[*1], **E. Adam Paxton**[1], **David Applegate**[1]*

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Abstract

Nuclear Waste Services (NWS) specialises in the management of the UK's nuclear waste, and its goal is to ensure that all radioactive waste is managed safely and securely through innovative and sustainable approaches. This includes siting and construction of the UK's Geological Disposal Facility (GDF) for higher activity radioactive waste. Some of the UK's waste contains large quantities of fissile nuclides, therefore a safe GDF design must account for the risk of a post-closure subsurface criticality event.

Fissile nuclides will be dispersed in a GDF over post-closure timescales governed by uncertain processes such as leaching, radioactive decay, corrosion, diffusion and reactive transport. To account for these uncertainties, NWS's approach is based on probabilistic modelling which computes thousands of radionuclides migration scenarios, by using a Monte Carlo tool (GoldSim). Previous assessments using existing models have used expert human judgement to select the worst-case scenario, which was then passed to a Monte Carlo neutron transport code (MONK® or MCNP®) to calculate neutron multiplication factor keff (i.e., reactivity).

However, identification of the bounding realisation from thousands of scenarios is challenging, especially for systems where concentrations of fissile isotopes and neutron absorbers vary substantially over time and between scenarios. To address this issue, a new codebase, GoldSim Monte Carlo Interfacing Tool (GMIT), has been developed by Jacobs to automate this process, calculating keff for all scenarios and identifying trends in reactivity.

This talk will discuss the main features of GMIT and will present some preliminary results, including reactivity trends that were not seen before.

15:10

Potential application of quantum computing to Monte Carlo radiation transport

Paul Smith*[1], Roberta Rehus[1], Konstantinos Georgeopoulos[2], Ines Juvan-Beaulieu[3]

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[*] Corresponding author email: **paul.smith8@jacobs.com**

Abstract

Monte Carlo simulation of radiation transport plays a key role in the nuclear and medical industries. Several processes contribute significantly to the computational cost of performing Monte Carlo radiation transport calculations: random number generation; nuclear database searches, ray tracing and the Monte Carlo process itself.

ANSWERS® supported by the National Quantum Computing Centre (NQCC) and Oxford Quantum Circuits (OQC) has made initial investigations into quantum computing approaches to these processes. In our presentation we discuss quantum random number generation, an established technique, and use of the Grover search algorithm. Approaches to quantum ray tracing and quantum Monte Carlo algorithms are also considered.

UK Research and Innovation, through the Engineering and Physical Sciences Research Council (EPSRC) and the Science and Technology Facilities Council (STFC), is leading a programme to establish the NQCC as part of phase 2 of the National Quantum Technologies Programme (NQTP). The NQCC represents a £93m investment over 5 years and will establish 4 key technology work streams: 100+ qubit NISQ demonstrator hardware platform(s); quantum software, algorithm & applications development; high performance, scalable qubit technology development; roadmap and architecture towards fault-tolerant general purpose quantum computing.

OQC, one of Jacobs' partners, is a globally leading Quantum Compute-as-a-Service (QCaaS) company that has developed powerful, enterprise-ready quantum computers. A key factor to OQC's success is its core, patented technology called the Coaxmon, an innovative superconducting qubit design with a 3D architecture.

Figure 1. OQC's 8 qubit quantum computer 'Lucy'

Keywords

Quantum computing, qubit, radiation transport, Monte Carlo

DAY 1 THURSDAY 9 NOVEMBER

SESSION 4: ALTERNATIVE FUEL, PLANT EXTENSION, END-OF-LIFE STUDIES AND FUEL CYCLE FACILITIES

16:00 **Keynote**

Accelerated licensing of nuclear fuels using mechanistic modelling methods

***S.Middleburgh*[*1]**

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Abstract

Novel nuclear fuels are being considered for use in current and next generation reactor systems, whilst some existing fuel designs are being taken out of their operational envelope for experience, and a route to rapidly license these fuels is being targeted. The involvement of mechanistic modelling methods with state-of-the-art experimental data and synthesised by the use of machine learning will allow the nuclear community to more readily meet the challenges that it must meet going forwards. In this presentation, we will discuss some of the challenges associated with composite fuels such as TRISO compacts, in order to highlight some of the key variations in the fuel performance codes that need attention. Additionally, we will look at some of the methods that can be used to produce the models required and the support that is necessary from the experimental and methods community to ensure targets are met.

Keywords

Nuclear fuel, next-generation reactor systems, TRISO fuel, mechanistic modelling

16:30 **PuO2 Modelling relevant to long-term storage**

Nathan Palmer*1, Dave Woodhead1, Owen Heaton1

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Abstract

The UK has a stockpile of circa 140 tonnes of separated civil plutonium arising from reprocessing of metal and oxide spent nuclear fuel from the UK and overseas. The stockpile comprises Magnox and Thermal Oxide Reprocessing Plant (THORP) plutonium dioxide (PuO_2), stored as powder in sealed cans at Sellafield. Fundamental understanding of the evolution and behaviour of gases within the cans is vital to ensure safe and secure storage with a key aim being to avoid pressurisation of the cans. Here, we report some modelling of PuO2 temperatures, adsorption of water and gas pressures, which used finite difference methods in gPROMS®.

For technique development, a simple self-heating 'rod' of PuO_2 was modelled, starting completely dry and with saturated water vapour present at both ends. The water vapour diffuses through powder voidage and is partially adsorbed. Figure 1 illustrates the predicted temperatures and number of water monolayers along the rod. Radiolysis of the adsorbed water, assumed pessimistically to generate both oxygen and hydrogen, was modelled and resultant partial pressures along the rod were predicted after taking account of generation and transport terms.

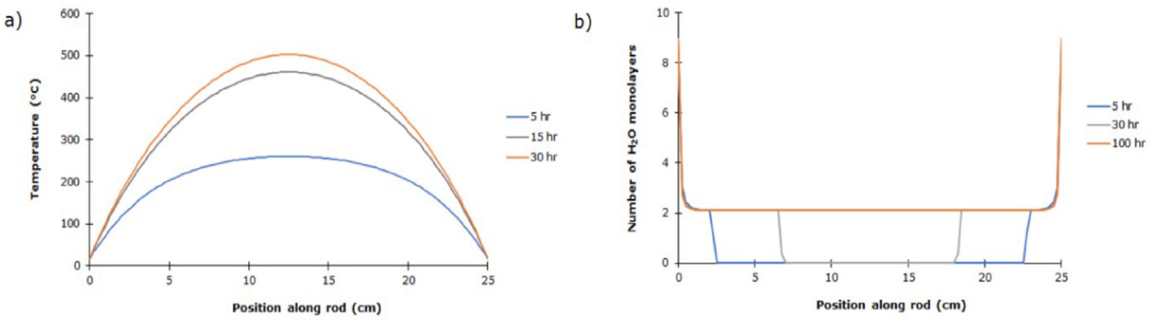

Figure 1: Predicted temperatures and adsorbed monolayers of water along a PuO2 rod.

Building on this modelling, PuO_2 can models are being developed. Temperature distributions in THORP and Magnox cans have been predicted, showing good agreement to experimental data. More recently, modelling of the adsorption and diffusion of water in the PuO_2 cans has been undertaken. Future work will extend these models to include heat transfer to the environment, water radiolysis and gas generation. This will be of relevance to long-term storage at Sellafield.

Keywords

Plutonium dioxide, storage, adsorption

DAY 1 THURSDAY 9 NOVEMBER

16:50 ## The last cycle of Tihange 2: reload design, safety evaluation and pool management

***R. Van Parys*[*1]*, M. Haedens*[1]*, M. Vanderhaegen*[1]

[1] Core & Fuel, Tractebel (Engie), Brussels, Belgium
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Abstract

In Belgium, the nuclear power plant Tihange 2 was phased out by law in February 2023 after 40 years of operation. Since for the last cycle, there were only a few months left, a core without fresh fuel assemblies has been loaded, making use of the remaining reactivity in the buffered fuel assemblies. Tractebel's in-house Loading Pattern Optimizer (LPO) helped in determining the optimum core reload with sufficient safety margins. The safety evaluation of this core showed some special characteristics with respect to previous reloads containing fresh assemblies. Therefore, complementary evaluations in addition to the standard cycle specific evaluation were required, where a pro-active discussion with the Belgian Safety Authorities was key. The core characteristics mainly required to recalculate the Departure from Nucleate Boiling Ratio (DNBR) for some accident state-points. Furthermore, a coupled re-evaluation of the Steam Line Break (SLB) accident with the Tractebel multiphysics platform CERES was performed, as a confirmatory study for margin management. In addition to the required verifications of the in-core behaviour of the fuel, the spent fuel pool unloading strategy was also challenged with this atypical core management strategy, confirming not only the end of the operational phase, but also the start of the post-operational phase.

Keywords

Phase-out, Reload, Strategy

17:10 **Development of safety analysis and management of residual risk**

***John Jones**[*1]*

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[*] Corresponding author email: **glos.e.papers@gmail.com**

Abstract

Site licences are conditional on a set of operating rules that define operating limits; based on a safety case submitted by the site licensee. In this presentation, changes to the safety case in response to major incidents are described and the effect on residual risk estimated.

Until the mid 1980s, the approach was deterministic; a design-basis fault at limiting operating conditions set protection with a high level of confidence, (assuming a single protection failure). The residual risk was mainly in faults at shutdown and external hazards, which were not systematically addressed.

Following loss of auxiliary feed at Oldbury,where core melt was narrowly avoided, external hazards were considered.

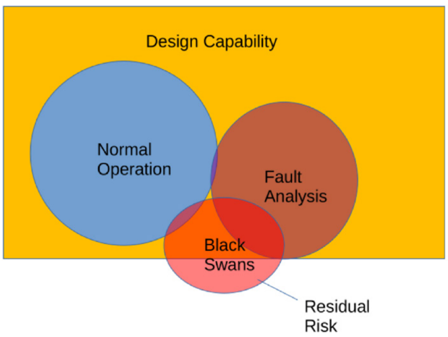
After Three Mile Island (TMI) accident, the use of probabilistic safety analysis (PSA) became more common.

After the Fukushima accident, additional measures were taken to ensure practical elimination of early or large uncontrolled releases and to enhance defence in depth.

This presentation discusses the rationale for the construction of safety cases and the strengths and weaknesses of each of these measures.

Keywords

Uncertainty, Defence in Depth, Deterministic Analysis, PSA.



17:30 **DAY 1 CLOSES**

DAY 2 FRIDAY 10 NOVEMBER

SESSION 5: PLANT PERFORMANCE IN ACCIDENT CONDITIONS

Chair: ***Prof. Panagiota Angeli***

08:30 **Keynote**

Severe accident modelling: A historic perspective, recent developments and challenges ahead

Luis E. Herranz [*1]

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Abstract

The inherent complexity of nuclear reactor severe accidents (SA) has highly conditioned the capability to reliably predict these scenarios from the beginning of the nuclear age. Nonetheless, noticeable accomplishments have been made along decades: from the initial simple correlations developed for the nuclear plant siting to the current integrated engineering tools, which are capable of simulating challenging multi-physics scenarios for days. The last generation of these analytical tools is numerically robust, phenomenological extensive, and supported by validation. This presentation provides an overview of the past and outlines what might be an alternative approach to severe accident analysis.

The adaptation of uncertainty and sensitivity analysis (UaSA) to its application in the SA domain, might open a new era for SA analysis, although these challenges are not minor. These cover areas such as a database on input deck uncertainties, and coupling of severe accident codes and statistical tools. In addition, these require an optimal procedure to deal with aspects like, bifurcation, crash runs or outliers. The EC MUSA (Management and Uncertainties of Severe Accidents) project became an outstanding means to identify those challenges and some potential ways to deal with them. However, there is still a need to make BEPU (Best Estimate Plus Uncertainty) a powerful and broadly used approach for severe accident simulation, and its harmonization. In other words, a consolidated and systematic methodology independent of any specific SA and statistical tool needs to be developed. This will be the purpose of the INNOMUSA (INNOvation in Management Uncertainties of Severe Accidents) project.

Keywords

Uncertainty quantification; sensitivity analysis; severe accidents simulation; MUSA Project

DAY 2 FRIDAY 10 NOVEMBER

09:00 Criticality safety and reactor physics modelling in stochastic geometries in the MONK® Monte Carlo code

Paul Smith* [*1]

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[*] Corresponding author email: **paul.smith8@jacobs.com**

Abstract

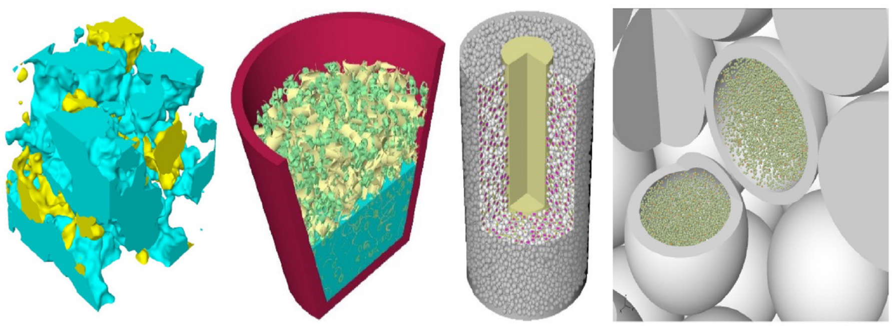
Stochastic geometries are of considerable interest for criticality safety, radiation shielding and reactor physics applications. Certain reactor designs, such as pebble bed and prismatic high temperature gas cooled reactors feature inherently random fuel geometries. Concrete is a common structural material, and is comprised of a random distribution of aggregates bonded with cement. Highly disordered geometries may arise in worst credible fissile material transport scenarios or severe reactor accidents, leading to requirements for modelling criticality safety in such highly random geometries.

The MONK® Monte Carlo code implements Woodcock tracking in its Hole Geometry package, which is very well suited to the modelling of stochastic geometries. The range and quality of stochastic geometries available in MONK are greater than those of any other production Monte Carlo code, with a number of well-established stochastic geometries. These include: random distributions of randomly sized spheres; random distributions of multicoated particles in spherical fuel pebbles; random distributions of fuel and moderator pebbles in pebble bed reactors; and randomly orientated rods in a cylindrical container. New stochastic geometries have recently been developed for the next version of MONK, including: highly disordered heterogeneous mixtures of two or more materials; random distributions of randomly-sized non-spherical shapes; and random distributions of multicoated particles in non-spherical geometries.

The validation of stochastic geometries may present challenges for regulatory acceptance. In order to address this challenge we will assess the applicability of the MONK Validation Database to stochastic geometries, and present results from an international benchmark exercise on criticality modelling in stochastic geometries.

Keywords

MONK, Monte Carlo, Criticality; Reactor Physics; Stochastic Geometry



DAY 2 FRIDAY 10 NOVEMBER

09:20 **Modelling of irradiation creep in graphite**

Dr. V. Zolotarevskiy*[*1], Dr. G.N. Hall[1], Prof. A.N Jones[1]

[1] Nuclear Graphite Research Group, Department of Engineering for Sustainability, Royce Institute, University of Manchester, UK

[*] Corresponding author email: **vadim.zolotarevskiy@manchester.ac.uk**

Abstract

The core of an advanced gas-cooled reactor (AGR) is comprised of graphite bricks that provide moderation and form channels for fuel rods, control rods, and coolant. The structural integrity of these core components is crucial for safe operation, and therefore, ongoing assessment of the deformation of and stresses in the graphite bricks during AGR operation is important.

This work focuses on the irradiation creep relationship used in the finite element (FE) modelling of AGR graphite bricks. The irradiation creep formulation in the FE analyses previously adopted the UKAEA creep model, and was based on the assumption that irradiation creep is the sum of primary and secondary creep, where only primary creep is recoverable. However, the existence of an additional recoverable creep component has been postulated for some time.

A revised irradiation creep model has been implemented in the FE user material code to include the extra recoverable creep component and support different CTE-irradiation creep relationships. A graphite brick was simulated using the FE software Abaqus and the results show lower values of stresses at power for the revised model compared to the UKAEA model. At shutdown the difference between the UKAEA and the revised creep models is less pronounced. It is also presented that the bore displacement is independent of the applied creep relationships.

Keywords

Finite element analysis, irradiation creep, advanced gas-cooled reactor

DAY 2 FRIDAY 10 NOVEMBER

09:40 **Multi-Physics Multi-Scale Simulation Framework Based on CTF/CTF Fuel**

***Maria Avramova**[*1]**, Agustin Abarca**[1]**, Pascal Rouxelin**[1]**, Gregory Delipei**[1]**, Muhammad Altahhan**[1]*

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[*] Corresponding author email: **mnavramo@ncsu.edu**

Abstract

The development, validation, and application of efficient and reliable Modelling and Simulation (M&S) capabilities have historically played a crucial role in designing, licensing, and operation of the current generation of nuclear reactors, and it is becoming equally essential for the design and licensing of small modular reactors (SMR) and advanced reactor designs. Multi-physics multi-scale simulation frameworks are employed to design, analyse, and operate nuclear reactor systems. This is because the different physics involved in reactor cores are usually tightly coupled with a variety of feedback parameters. The strong feedback effects therefore require different linked/coupled codes working in tandem to accurately simulate the coupled reactor core/system behaviour. Innovations in nuclear engineering and associated domain sciences, especially computer science and high-performance computing hardware, have enabled a wide range of high-fidelity applications letting the scientific and engineering community to gain insights into physical systems in ways not possible with traditional approaches alone. In the last few years, the combination of the relatively efficient traditional M&S with more costly novel high-fidelity simulations is raising in popularity as it can emulate the high-fidelity model at cheaper computational cost. To address the integration of high-fidelity and low-fidelity codes to predict quantities of interests in an efficient manner, a framework of High-to-Low (Hi2Lo) model informing procedures is usually utilized for each physics M&S in a reactor core and combined in multi-physics simulations. Such innovative frameworks improve the modelling of the local effects without compromising the computational costs and will result in more efficient and accurate predictions of safety parameters and margins. These developments are of high importance for both safety and performance improvements as well as for enabling the end users with credible and efficient tools for the design, analysis, and licensing of advanced nuclear systems. This presentation focuses on the development of efficient and improved core thermal-hydraulics and fuel performance predictive capabilities for M&S at the North Carolina State University (NCSU) and closely related or supporting developments of neutronics and system thermal-hydraulics modelling. NCSU develops and maintains the advanced core thermal hydraulics/fuel modelling software package CTF/CTFFuel for Light Water Reactor (LWR) analysis with recent developments have enabled and improved their capability to model SMR and advanced reactor systems. These codes have been coupled with corresponding tools to develop a multi-physics multi-scale platform with High-to-Low (Hi2Lo) model informing procedures which are discussed along with obtained results and future activities.

Keywords

Multi-Physics, Multi-Scale, Simulation Framework

10:00 **BREAK**

DAY 2 FRIDAY 10 NOVEMBER

SESSION 6: REACTOR THERMAL HYDRAULICS, FUEL PERFORMANCE, NEUTRONICS, CRITICALITY AND SHIELDING

Chair: ***Prof. Kostadin Ivanov***

10:20 **Keynote**

Mathematical modelling of intensified flowsheets for spent nuclear fuel reprocessing

Prof. Panagiota Angeli, Prof. Eric Fraga*, Dept of Chemical Engineering, Faculty of Engineering Science, University College London*

Abstract

Commercial plants for spent nuclear fuel reprocessing are typically based on the Plutonium Uranium Extraction (PUREX) process. The PUREX process uses traditional liquid-liquid extraction technologies. Alternative intensified processes may be more efficient, safe, and economic. Such alternatives, based on small-scale extractors, may overcome some of the issues related to the conventional technologies, such as solvent degradation, large size, and nuclear criticality control.

In this talk, we address the modelling of intensified operations using small channels and the use of these models in an optimization based framework for design. The modelling includes mass transfer, redox reactions, pressure drop, and nuclear criticality, as well as manifold and two-phase separator designs. The resulting design model, posed as a superstructure optimisation problem, is a mixed integer nonlinear problem, implemented in the General Algebraic Modeling System (GAMS).

The case study presented is the production, during reprocessing, of a mixed uranium/plutonium oxide instead of pure plutonium to preclude the risk of nuclear proliferation. The product is suitable for mixed oxide fuel fabrication. Novel designs are compared with conventional liquid-liquid extraction technologies such as mixer/settlers and pulsed columns, using models from the literature. The results show that the small scale technology could be beneficial, in particular in terms of volumetric mass transfer coefficients, nuclear criticality safety and short residence time, which improves neptunium separation and reduces solvent degradation.

10:50

Study of energy deposition in the coolant of LFR

Maria Susini* [*1], ***Daniele Tomatis*** [2], ***Stefano Argirò*** [1]

[1] Dipartimento di Fisica, University of Turin, Turin, Italy, [2] newcleo srl., Turin, Italy
[*] Corresponding author email: maria.susini@edu.unito.it

Abstract

Reactor calculations couple different physical models to describe the amount of energy released and deposited in the materials building the reactor. In particular, during reactor operation the production of thermal energy in the core from nuclear reactions must be balanced by heat removal by the coolant. The behaviour of the coolant is governed by thermal-hydraulics, showing enthalpy rise in the fluid for the thermal flux at the outer surface of the fuel rods and because of internal energy release due to particle interactions. These two mechanisms yield different heat transfer dynamics. Energy deposited in the coolant must be carefully estimated even if it is of small amount with respect to energy deposited in the fuel. This work studies energy deposition by radiation in lead-cooled fast reactors (LFR) using the Monte Carlo computer code OpenMC. Details of the numerical simulations are explained, including the simplifications made in the study to approximate the transport of photons and neutrons in lead. Several physical states of the reactors are also considered to estimate coolant heating by local energy deposition.

Keywords

LFR, coolant heating, Monte Carlo calculations.

DAY 2 FRIDAY 10 NOVEMBER

11:10 **A reduced order model discretisation of the space-angle phase-space dimensions of the Boltzmann transport equation with application to nuclear reactor eigenvalue problems**

A. G. Buchan[1]

[1] School of Engineering and Materials Science, Queen Mary University of London, Mile End Road, London, E1 4NS
*Corresponding author email: **a.buchan@qmul.ac.uk**

Abstract

This article presents a new reduced order model for ultra-fast solutions to neutron transport problems. The novelty lies in the construction of optimal basis functions spanning the space-angle phase-space dimensions of the Boltzmann transport equation. It uses Proper Orthogonal Decomposition and the method of snapshots to form the reduced basis, but here a 2-stage construction is proposed that compresses the angle, then space, dimensions sequentially. The approach reduces the computational memory burden of processing the full discretised solutions of Boltzmann transport equation (BTE) during the construction stage - a potential issue for large scale problems. The reduced model is both accurate and efficient to solve, and this is demonstrated by solving a criticality problem involving a small 2-dimensional quarter reactor core with assumed uncertainties in nuclear cross-section data.

Reductions in problem size and solving times exceed several orders of magnitude in comparison to a full discretised model of similar accuracy. These gains would be expected to further increase for larger scale reactor problems.

Keywords

Reduced Order Models, Neutron Transport, Eigenvalue

DAY 2 FRIDAY 10 NOVEMBER

11:30 **Finite Element Analysis of the effects of eccentric fuel stringers on the predicted onset of brick cracking**

Dr. A. Farrokhnia*, Dr. G.N. Hall and Prof A.N. Jones

Nuclear Graphite Research Group, Department of Engineering for Sustainability, Royce Institute, University of Manchester, UK
* Corresponding author email: **ahmadreza.farrokhnia@manchester.ac.uk**

Abstract

Approximately 15% of the UK electricity is produced by the eight remaining Advanced Gas-cooled Reactors (AGRs). These AGRs are operating beyond their design life and are subject to ageing and degradation mechanisms. It is essential that those mechanisms are adequately characterised to ensure safe operation. This study presents work commissioned to understand one particular aspect of the uncertainties in those mechanisms.

At the heart of an AGR is a graphite core made up of a large array of interlinked graphite bricks which provides neutron moderation, structural integrity and cooling flow for fuel. The operating environment (e.g. neutron and gamma irradiation) induces dimensional changes and oxidation of the graphite bricks. The irradiation alters the material properties of the graphite material and induces stresses within the graphite bricks. These stresses can induce full height axial cracks initiating at the external keyway roots, known as keyway root cracks as shown in figure 1. Individual cracked bricks will not impact safe operation but the timing and rate of accumulation of cracked bricks can affect station lifetimes. Hence, characterising uncertainties in the timing and rate of accumulation is important to maintain confidence in the safe operation of the remaining AGRs.

The licensee has postulated that fuel stringer bowing may result in an asymmetrical temperature profile in the fuel bricks, thereby changing the stress and therefore affecting the timing and rate of cracked brick accumulation in the reactors. This study presents an investigation using finite element (FE) analysis of a fuel brick to characterise how an eccentric fuel stringer affects the stresses within a graphite brick and ultimately cracking.

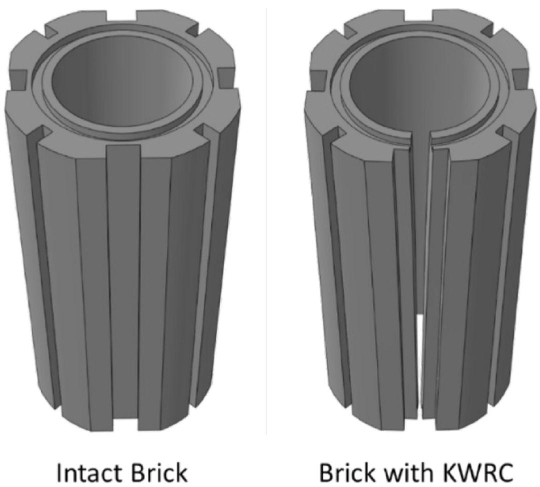


Figure 1. Graphite moderator brick before and after a keyway root crack (KWRC)

Keywords

AGR, Nuclear Graphite, Eccentric fuel stringer, Keyway Root Cracking

DAY 2 FRIDAY 10 NOVEMBER

11:50 **Design and optimisation of a boron-free small modular reactor core**

Bright Madinka Mweetwa*[*1], Marat Margulis[1]

[1] Bangor University, Nuclear Future Institute, Bangor, North Wales
[*] Corresponding author email: **brm22kcj@bangor.ac.uk**

Abstract

Boric acid is traditionally used for reactivity control in pressurised water reactors. However, it causes corrosion in reactor components. The indirect effect is increased operational radioactive waste from neutron-activated corrosion fragments. During reactor operation, chalk riverbed unidentified deposits (CRUD) accumulate on the fuel cladding in regions of high burnup. Compounds of boron have been found in these deposits and they cause distortion in neutron flux distribution. This leads to axil-offset anomaly (AOA) which is a deviation in axial power profile prediction. Accumulation of deposits can reduce plant efficiency to about 70 % over time. The current research work seeks to design a soluble boron-free Small Modular Reactor (SMR) core. As a first step in the design process, a borated variant of the target boron-free SMR core has been designed and is being used as a reference core. Results obtained from the reference core are used to ensure that the boron-free core is designed within acceptable safety margins. The design process and calculations of nominal and off-nominal parameters for the variant and the target core have been carried out using CASMO4e, CMSLINK, and SIMULATE3 codes. A comparison of evaluated reactivity coefficients and spatial xenon oscillation indices for the two cores show agreement. Both cores show stability with respect to spatial xenon oscillation. Their spatial xenon oscillation indices were determined to be negative. A negative stability index indicates that a core has xenon oscillation self-damping capabilities. An extract from the results on xenon spatial oscillation evaluation is presented in

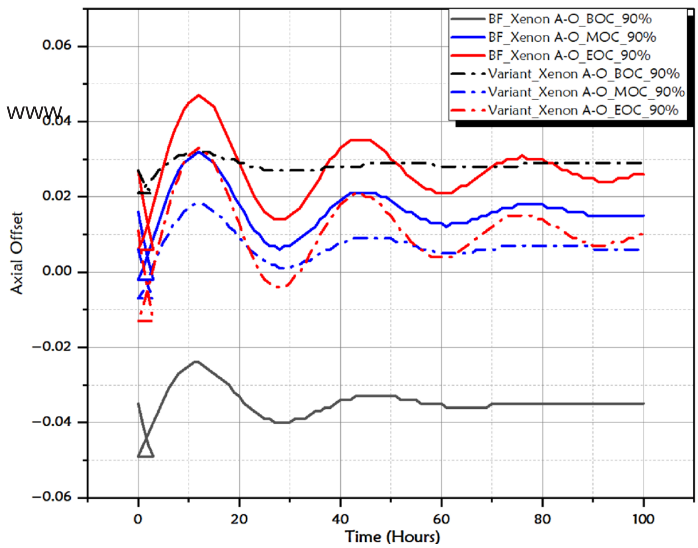


Figure 1. A comparison of xenon axial oscillations due to a 90% power perturbation for a borated and a boron free core.

Keywords

CRUD, stability-index, burnable-poison

DAY 2 FRIDAY 10 NOVEMBER

12:10 **LUNCH, POSTER SESSION and NETWORKING**

SESSION 7: OPTIMISATION TECHNIQUES TO SUPPORT DESIGN AND PROCESS DEVELOPMENTS

Chair: ***Dr Mark Bankhead***

13:30 An open-source porous media modelling approach to investigate thermohydraulic features of compact printed circuit heat exchangers

Michael McDermott*[1], Shuisheng He[1]

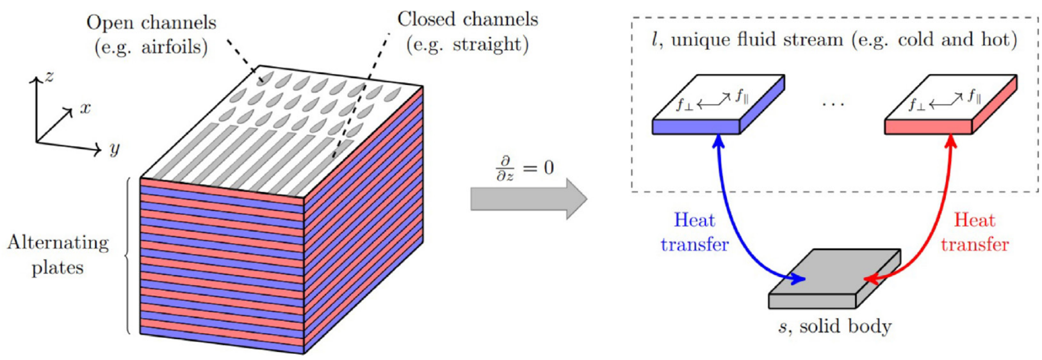
[1] Department of Mechanical Engineering, University of Sheffield, Sheffield, United Kingdom
* Corresponding author email: **m.mcdermott@sheffield.ac.uk**

Abstract

An experimental air-foil printed circuit heat exchanger (PCHE) with CO2 as a working fluid is numerically modelled and developed within the OpenFOAM environment as a freely available package. The conjugate heat transfer solver (chtMultiRegionFoam) is adapted to include both the hot and cold fluid streams of the PCHE, along with the solid recuperator body, within three uniquely specified overlapping 2D mesh regions. The fluid stream momentum equation is adapted to incorporate porosity, with the additional stream-wise air-foil drag (friction factor) accounted for by the Darcy-Forcheimer porous media model. A simple linear ad-hoc model for the transverse friction factor is assessed to determine cross-flow momentum dispersion. Heat transfer between the fluid streams and the solid body is driven by a volumetric thermal resistance with a cell volume-weighted interpolation method (volume-to-volume coupling), with experimentally determined Nusselt number correlations applied. The temperature-dependent parameters based on isobaric NIST data for CO2 are tabulated as a user library and integrated within the coding package. The model predictions of the solid body temperature distributions are assessed and validated against experimental data with eight equidistant fibre optical measurements across the PCHE core, and also compared against a finite-element based MATLAB numerical results. Thermal stresses are evaluated and qualitatively assessed against experimental data, demonstrating the model capabilities in highlighting potential design features for improvement.

Keywords

Nuclear thermohydraulics; OpenFOAM; Printed Circuit Heat Exchanger



DAY 2 FRIDAY 10 NOVEMBER

13:50 Modelling the liquid waste operation at the Savannah river site

Andrew Jung*[*1], TannerLiddy[1], JeremyBas[2], AndreasGeorgiou[2], SimonWoodward[2], Peter Hill[1], Scott Williamson-Owens[2]

[1] Savannah River Mission Completion (SRMC), Aiken, South Carolina, United States of America
[2] DBD Limited, Warrington, United Kingdom
[*] Corresponding author email: **andrew.jung@srs.gov**

Abstract

The Savannah River Site, located in Aiken, South Carolina, stores 34 million US gallons of radioactive liquid waste in 43 underground waste tanks. The United States Department of Energy's Office of Environmental Management (DOE EM) awarded Savannah River Mission Completion, LLC (SRMC) the contract to process the liquid waste and to close the waste tanks. SRMC's System Planning Group has collaborated with DBD Limited (DBD) to develop a Modelling toolset to predict the performance of the waste treatment system and identify improvements.

The toolset utilizes a subset of technologies to achieve a holistic forecast that simulates the logistical and chemical realities of the SRMC mission. The Program Optimization Model (POM) is a discrete event simulation model that houses the logistics, decision logic, and the gross balance of material transfer. The Technical Optimization Model (TOM) is a dynamic simulation model that addresses fundamental and site-specific chemical processes and tracks chemical constituents of interest. The combination enables a rapid and comprehensive evaluation of facility improvements, where previously chemical and logistical impacts would be independently evaluated.

Improved reporting tools have drastically expediated output analysis and communication. Custom reporting graphics are now automated and are appended with data-driven facility simulation insights. The toolset has also expanded SRMC System Planning's capabilities to support the waste treatment system's strategic and tactical scopes. Future improvements in mission optimization and stochastic simulation will address navigating risk as the mission progresses.

Keywords

Nuclear Waste Processing, Lifecycle Modelling, Strategic Planning

14:10 Differential evolution optimization of a nuclear thermal propulsion rocket

Kimberly Gonzalez*[*1], William Culbreth[2]

[1] Department of Mechanical Engineering, University of Nevada Las Vegas, Las Vegas, NV, USA
[*] Corresponding author email: **gonzak2@unlv.nevada.edu**

Abstract

During the 1960's and 70's, U.S. Project ROVER and NERVA developed and tested nuclear thermal propulsion rocket engines. The designs developed are still referenced today to design new NTP rockets. Although previous designs were successful, providing a specific impulse twice that of chemical rockets, limited computer power made it difficult to calculate optimal designs based on reactor weight, specific impulse, and fuel element shape. An optimizer written in C and using MCNP has been created based on a differential evolution algorithm to find the optimal mass flow rate of hydrogen, optimal reactor power, and reactor inlet pressure that provides the highest specific impulse. A novel molten fuel reactor was optimized with a design based on the Pewee I NTP rocket with 111 kN of thrust. Constraints and geometry were first defined in the C program. The program then developed candidate designs based on previous successful designs through iteration while maximizing the specific impulse. The dimensions of the reactor were also used in MCNP to ensure that it could maintain criticality. Use of optimization techniques are strategic in the efficient design of NTP reactors with high thrust and specific impulse and with low reactor and propellant weight to aid in manned missions in space.

Keywords

Nuclear Thermal Propulsion, Optimization, Specific Impulse, High Temperature Reactors

14:30
Phase Field modelling of low-cycle fatigue behaviour of nuclear structural materials

Md.Zahid Hasan * *and* ***Abdullah Al Mamun***

Nuclear Futures Institute, Bangor University, Bangor LL57 1UT, United Kingdom
* Corresponding author email: **mdh23rct@bangor.ac.uk**

Abstract

In the last decade, phase field fracture models have been implemented widely to simulate the failure of engineering materials under various loading conditions. Among these failure analyses, the high-fidelity analysis of fatigue crack nucleation and evolution using phase field method has attracted particular interest, since fatigue damage depends on the coupled effect of arbitrary loading histories, dimensions, and complexity of physical phenomena. Numerous past studies have proposed dissimilar phase field models to address the high-cycle fatigue of materials, assuming material deformation as elastic. The structural materials in nuclear power-plants, in contrast, experience cyclic elasto-plastic strain under changing thermo-mechanical loading causing low-cycle fatigue. To interrogate this low-cycle fatigue, this study has developed a phase field model able to capture the plastic deformation of material at the crack tip under strain-controlled cyclic loading. The model, in addition, considers the influence of cyclic hardening of materials on fracture toughness and crack growth rate. Implementing the model, low-cycle fatigue can clearly be demarcated from high-cycle fatigue in terms of crack surface irregularity. When fully fetched, the model will be able to inform the nuclear life assessment procedures for accurate prediction of materials life in nuclear service conditions.

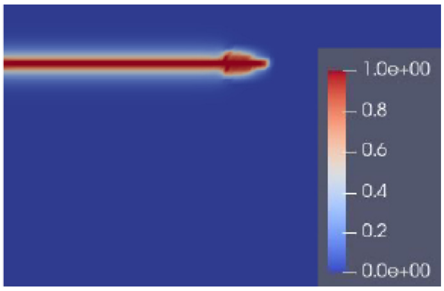


Fig.1 – Crack propagation in nuclear materials simulated using phase field method.

Keywords

Phase field model, low-cycle fatigue, crack nucleation, structural materials failure, nuclear materials

14:50 CLOSING REMARKS AND FEEDBACK

POSTERS

POSTER 1

A MECHANOCHEMICAL FORMULATION FOR HIGH STRAIN DISSOLUTION DRIVEN STRESS CORROSION CRACKING

Jason Lee[1], Mark Wenman[1], Emilio Martínez-Pañeda[2], Sasa Kovacevic[2], Maciej Makuch[1]

[1] Centre for Nuclear Engineering and Department of Materials, Imperial College London, Prince Consort Road, London SW7 2AZ, United Kingdom
[2] Department of Civil and Environmental Engineering, Imperial College London, London SW7 2AZ, UK
[*] Corresponding author email: **jason.lee18@imperial.ac.uk**

Abstract

Corrosion is a costly phenomenon that affects even stainless-steel components. In the nuclear industry, serious corrosion problems have led to safety concerns and resulted in the shutdown of many reactors. Understanding the root causes behind corrosion is vital in preventing such incidents from occurring.

Expanding on existing mechanochemical coupled finite element models of stress corrosion cracking, we present a new theoretical and numerical framework focusing on high strain environments. Dissolution kinetics during dynamic recovery is characterised and shown to have a significant effect on crack growth rates. The origin of existing mechanochemical effects on dissolution kinetics is reviewed and extended to high strain regions. The phase field model considers, for the first time, the role of cold work and the cross-slipping mechanism in mechanically-assisted corrosion. A complex relationship between local strain and crack length is revealed and indicates a maximum mechanical influence resulting from dislocation pile-ups. The results obtained are useful to explain experimental observations and assessing infrastructure at risk of stress induced corrosion.

Keywords

Phase field, Stress corrosion cracking, Stainless steel, Effects of strain, Mechanochemistry

DAY 2 FRIDAY 10 NOVEMBER

POSTER 2

ELECTRON CONDUCTIVITY IN UN WITH SI, C AND O IMPURITIES

Cintia Leite Goncalves*[*1], Robert Annewandter[1], Antoine Claisse[2], Simon C. Middleburgh[1]

[1] School of Computer Science and Electronic Engineering, Bangor University, Bangor LL57 1UT, UK
[2] Westinghouse Electric Sweden AB, Vasteras, Sweden
[*] Corresponding author email: **cng22qhr@bangor.ac.uk**

Abstract

Purity control in the generation of nuclear fuels is of essential importance, especially when addressing their impacts in terms of in-reactor performance. This influence of impurities on thermal conductivity, a key property of a nuclear fuel, is considered by the study of electronic conductivity in the case of uranium nitride and factors such as the impact of purity, temperature, presence of impurities, and defects are essential for licensing for industrial use. As uranium nitride's thermal conductivity is dominated by the movement of electrons in the material, this work focused on observing its thermal conductivity and resistivity, counting impurities C, Si, and O in the proportion of 12.5% using the first principles of the Functional Theory of Density (DFT) using tools such as VASP and BOLTZTRAP2, state-of-the-art methods, including evaluation of the Wiedmann-Franz Law. Electronic thermal conductivity growth with increasing temperature for both, pure uranium nitride, in this case, continues with the highest Ke 26.7 W/K.s at 1900 °C, however, Si impurities results in the lowest value at that temperature with Ke 20.6 W/K.s. Regarding resistivity, Si containing UN and oxygen containing UN at 800 K present similar resistivity around 3.63x10-6. It is concluded that when adding an atom as a dopant to the atomic structure of uranium nitride, different properties are observed, which is also influenced by the size of the cell (unit or supercell) under analysis.

Keywords

Electron conduction, impurities, and Uranium Nitride

POSTER 3

VALIDATION OF ACTIVITY DISTRIBUTION RECONSTRUCTION USING MLEM, SART AND BOUNDING CASES

Iona Webster*[*1], Paul Hulse[2], Joachim Bennett[3]

[1] Radiometric Systems Group, Sellafield Ltd, Whitehaven, UK
[2] Highly Active Liquor Strategy and Technical, Sellafield Ltd, Whitehaven, UK
[3] Highly Active Liquor Strategy and Technical, Sellafield Ltd, Whitehaven, UK
[*] Corresponding author email: **iona.webster@sellafieldsites.com**

Abstract

A novel technique has been developed to estimate the type, location and abundance of highly active solids in vessels undergoing decommissioning to inform the way they are washed out. Our activity distribution reconstruction technique involves applying MLEM and SART to dose rate measurements and modelled response matrices and comparing the dose profile to simulated scenarios to bound the estimate.

The response matrices are generated using models of the vessels created in MCNP. To validate the techniques, we have used the response matrices to simulate dose rates from known activity distributions and then compared the modelled activity distributions against these. We have also artificially introduced noise to the response matrices to mimic uncertainty associated with measurement data.

MLEM and SART gave more accurate and realistic results than other algorithms such as ART and the Moore-Penrose Inverse. As they are iterative algorithms, the results are dependent on how many iterations are performed and the initial guess we start with. A homogeneous initial guess was found to be best. The results become more accurate for the first few iterations and then become less accurate with increasing iterations due to noise in the problem. We are therefore investigating stopping rules to make the technique more consistent.

We have also used non-algorithmic techniques to bound the activity distributions, and these have proved to be a reliable second method to increase the robustness of results provided using the algorithms.

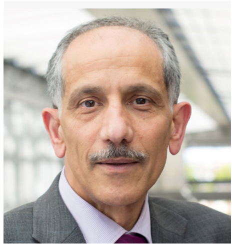
The technique will continue to be used and developed further to aid decommissioning on the Sellafield site.

Keywords

MCNP, MLEM, SART, validation, stopping functions

BIOGRAPHIES

Professor Ali Tehrani, CEng, FNucl, FIMechE



Office for Nuclear Regulation

Professor Tehrani has considerable experience of the nuclear industry in a wide range of roles, many at a senior level, developing safety enhancements, codes and methods supporting many operating facilities.

Ali is a Principal Nuclear Safety Inspector at the Office for Nuclear Regulation (ONR) and has led the assessment of UK-EPR and AP1000 designs in the areas of Fault Studies, Severe Accident and containment thermal hydraulics performance within the UK's Generic Design Assessment and construction.

He works closely with international regulators to enhance plant safety features at the design stage by focusing on regulatory concerns and safety standards, and supports the development of strategic research activities by OECD NEA, and also played a leading role in ONR's response to the events at Fukushima Daiichi.

Ali is a Visiting Professor at Imperial College London and leads a number of challenging and complex research activities developing CFD and multi-physics codes to improve understanding of the plant performance in accident conditions.

Panagiota Angeli

Panagiota Angeli is a Professor in the Department of Chemical Engineering at UCL, Deputy Head ED&I, and leads the ThAMeS Multiphase group. She obtained a Diploma in Chemical Engineering from the National Technical University of Athens, Greece, and a PhD on Multiphase Flows from Imperial College London. She specialises on multiphase flows, particularly those involving two immiscible liquids and their applications to continuous and intensified processing for energy and manufacturing applications. Her research combines advanced experimental studies, including laser based flow diagnostics, with mechanistic modelling and numerical simulations. Panagiota's work has been supported by substantial UK Research Council and European Union grants and by industry. She has been awarded a RAEng/Leverhulme Trust Fellowship to study continuous intensified separations with ionic liquids of uranium and lanthanides, relevant to spent nuclear fuel reprocessing, and guest edited the ChERD Nuclear Process Engineering Special Issue (2013). She is currently leading the Advanced Separations theme of the flagship EPSRC grant Atlantic on nuclear fuel cycles. Panagiota has published over 180 peer reviewed journal papers and has participated and chaired UK EPSRC and international (Norway, Sweden, Ireland, Belgium) research funding review panels. She co-chairs the Multiphase Flows Special Interest Group of the EPSRC funded UK Fluids Network.

Anwar Beg

I am the Director of the Multi-Physical Engineering Sciences Research Group (Corrosion Lab). Our group has other members - Dr Ali Kadir, Dr Henry Leonard, Dr Walid Jouri, Dr Martin Burby, Dr Sireetorn Kuharat, and Dr Ganapathy Sengodan. Our work spans simulation in biomedical, renewable energy, manufacturing, propulsion, marine and environmental applications. I have been UK editor for the Journal of Mechanics in Medicine and Biology (Singapore/USA) since 2010 and have coordinated many contributions in the areas of biological heat and mass transfer. I have co-edited a special volume, Modelling and Simulation in Engineering Sciences (2016) which attracted dozens of international contributions. I have also published 10 invited book chapters on state-of-the-art techniques including computational bio-nano-fluid dynamics (Computational Approaches in Biomedical Nano-Engineering, Wiley, USA, 2019) and multi-physical electro-magnetic propulsion fluid dynamics (Mathematical Modelling: Methods, Applications & Research, Nova Science, New York, 2018). Thus far I have published 650 journal papers in many leading journals including Physics of Fluids (USA), ZAMP (Germany), ZAMM (Switzerland), Int. J. Hydrogen Energy (USA), Materials Science and Engineering B (USA), Tribology International (France), IMECEH J. Process Mechanical Engineering (UK), IMECHE J Engineering in Medicine (UK) and ASME J. Biomechanical Engineering (USA). Since joining Salford in March 2016, I have produced over 330 journal papers. My google scholar h-index is 66 with 19,000 citations. Recently I achieved the distinction of being the 18th highest ranked research scientist in mechanical and aerospace engineering in the UK (Research.com). I have been ranked number one in engineering at Salford for research outputs for seven consecutive years (2016-2023). I have won several awards in recent years for my research including a Vice Chancellor Research Excellence Award (2018) at Salford University and first Prize for computational nano-pharmacodynamics at the “Materials of the Future: Smart Applications in Science and Engineering E-Conference”, Qatar University, March (2021). I have supervised 40 MSc dissertations and 3 PhD students at Salford in CFD simulation of solar nanofluid collectors, high temperature gas turbine blade corrosion protection with micro/nano-coatings and theoretical stress analysis of engineering components. My research has in multi-physical modelling includes electro-kinetic nanofluid dynamics, biomagnetic fluid dynamics, carbon nanotubes, machine learning in speech recognition, diabetic retinopathy and hydrocephalus transport. I am a chartered mechanical engineer and FIMECHE. I am also a Chartered Mathematician and FIMA. My most recent research has developed new approaches for geothermal hydrodynamic stability with explosive reactions, Taylor dispersion in electro-bio-microfluidics, swirling ferromagnetic fluid coatings, robotic swimming in oceans and rivers, Stokesian dynamics in droplet simulations, pulsatile flows in cardiac bifurcations, interfacial duct two-phase magnetohydrodynamics, radiative turbulence in nuclear reactor ducts, dielectric hydrogen rotating Hall and Faraday MHD generators, Joule heating in plasmas, artificial neural networks in magnetic coatings, tornado and tsunami dynamics, landing gear impact and tri-propellant rocket combustion. Our MPESG group uses ANSYS and many other computational tools.

Dr. Maria Avramova

Dr. Maria Avramova is a Professor in the Nuclear Engineering Department at North Carolina State University (NCSU). She also serves as a Director of the Consortium for Nuclear Power at NCSU and Coordinator of the CTF Users' Group. Dr. Avramova has been named 2020-21 North Carolina State University Faculty Scholar and has received the 2022 North Carolina State University Outstanding Global Engagement Award. Dr. Avramova is American Nuclear Society (ANS) Fellow.

Dr. Avramova earned her Ph.D. degree in nuclear engineering from Pennsylvania State University (PSU) in 2007. Prior joining to PSU, she held a research scientist position at the Institute of Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences, Sofia, Bulgaria. Between 2008 and 2015, Dr. Avramova held a post-doctoral scholar and an assistant professor position at PSU.

The research interest of Dr. Avramova includes nuclear reactor core thermal-hydraulics and design, transient and safety analysis, multi-physics and multi-scale simulations, verification, validation, uncertainty and sensitivity analysis.

Dr. Avramova had directed twenty-four (24) PhD's, twenty-five (25) MS's, forty-six (46) MEng's and seventeen (17) visiting scholars; and had sponsored four (4) post-doctoral fellows. Dr. Avramova had served in ten M.S., Ph.D. and Sc.D. committees in foreign academic institutions.

Over the years, Dr. Avramova has led several high visibility international programs supported by the Nuclear Energy Agency of the Organization for Economic Cooperation and Development (NEA OECD), International Atomic Energy Agency (IAEA), US Nuclear Regulatory Commission (NRC), and US Department Of Energy (DOE). She is a chair of the NEAOECD Expert Group on Core Thermal-Hydraulics and Mechanics (EGTHM).

Dr Mark Bankhead

Dr Mark Bankhead is a scientist with over 20-years of experience working in the nuclear industry. His work involves the development of complex mathematical models of chemical behaviour. This ranges from modelling the behaviour of atoms and molecules, through to understanding the impact of chemistry on process behaviour. He plays an digital technologies for NNL and playing an active role with the Nuclear Institute chairing the AI4Nuclear group.

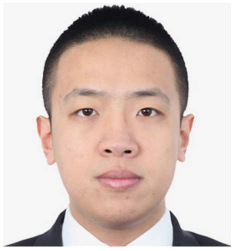
Madinka Bright Mweetwa

Madinka Bright Mweetwa is a PhD student at Bangor University, School of Computer Science and Electronic Engineering. His PhD work focuses on designing a boron-free small modular reactor (SMR) core. He is affiliated with the nuclear design and thermal-hydraulics research group under the Nuclear Futures Institute. His PhD is sponsored by the International Atomic Energy Agency (IAEA) and Bangor University. Bright has more than 10 years' experience in nuclear and radiation fields and has previously been involved in evaluating the safety parameters of Ghana's Research Reactor (GHARR1) after 20 years of operation. He used MCNP5, REBUS, and RELAP codes for the evaluation work. In addition, Bright has also been involved in developing methods for Large Sample Neutron Activation Analysis (LSNAA) using Gamma Spectroscopy. From an academic perspective, Bright has been involved in developing a curriculum for a master's programme in nuclear science and technology (Nuclear Engineering and Nuclear Medicine) and from a policy perspective; he has been involved in developing nuclear policies and laws for Zambia's nuclear programme. Under Zambia's nuclear programme, he was the lead and IAEA focal point in the development of Zambia's nuclear infrastructure in line with the IAEA's milestones approach.

Dr Andrew Buchan

Dr Andrew Buchan is senior lecturer in Engineering Science, Queen Mary University of London, and honorary lecturer Imperial College London. He specialises in computational methods for multi-physics modelling of radiation, fluids flow and heat transfer with applications to nuclear engineering, environmental flows, pollution dispersion, UVC light for disease control in air and chemical removal in drinking water. He 20 years experience in academia, has won over £8 million in research funding including an EPSRC early career research fellowship focusing on predictive modelling of nuclear reactors.

Boyang Chen



I am a Research Assistant at Applied Modelling and Computation Group (AMCG), Department of Earth Science and Engineering, Imperial College London. I am currently working on the UKRI-funded INHALE Project (Health assessment across biological length scales for personal pollution exposure and its mitigation) and the EPSRC-funded CO-TRACE project (Covid-19 transmission risk assessment case studies – education establishments), where I undertake the work on numerical modelling and AI prediction of airborne disease spread at indoor spaces. My area of expertise is Computational Fluid Dynamics (CFD) and my research mainly focuses on multiphase flows, including the suspension of solid particles in the air, sediment transport in rivers and airborne spread of virus through aerosols. During my PhD, I am the main contributor to the home-made CFD FORTRAN code Hydro3D and developed novel Eulerian-Lagrangian framework applied to solve environmental flows.

Alessandra Del Masto

After a PhD in mechanics obtained at the Femto-st institute in Besançon (France) I carried out two post-doctorates, the first at the “Institut de Radioprotection et de Sûreté Nucléaire”, (IRSN, Laboratory of Statistics and Advanced Methods, PSN-RES/SEMIA/LSMA, France) and the second at the Interdisciplinary Center for Nanoscience in Marseille (CINaM, France), both focusing on on material science and statistics.

I have now joined the Laboratory of Fuel Study and Modeling at the IRSN (PSN-RES/SEMIA/LEMC) to contribute to the research on the behavior of nuclear fuel rods, and to participate in the software development for the Fuel+ platform.

Ahmadreza Farrokhnia

Ahmadreza Farrokhnia is a research associate specialising in nuclear graphite within the Nuclear Graphite Research Group at the University of Manchester. He holds an undergraduate degree and a doctorate in nuclear engineering from the same institution. During his doctoral studies, Ahmadreza successfully developed a full-scale finite element model of an Advanced Gas-cooled Reactors (AGR) graphite moderator, showcasing his expertise in the field.

Currently working as an advisor for the Office of Nuclear Regulations, Ahmadreza is entrusted with the crucial responsibility of performing stress analysis on operating reactors. His work plays a part in ensuring the continued safe operation of the existing AGR fleet, making a tangible impact on the nuclear industry. Ahmadreza’s proficiency as a Finite Element Modeller enables him to excel in this demanding role, utilising his technical prowess to evaluate the structural integrity of the graphite cores and mitigate potential risks.

Furthermore, Ahmadreza’s current focus lies in the development of a specialized code capable of facilitating analysis on a large array of the current AGR reactors. This forward-thinking endeavour demonstrates his dedication to enhancing analytical capabilities and pushing the boundaries of research in the field.

With his deep knowledge, analytical skills, and expertise in nuclear engineering, Ahmadreza is consistently striving to expand his expertise and contributions to the advancement of reactor safety and safe operation.

Kimberley Gonzalez

Kimberly Gonzalez, a Las Vegas native, holds a Ph.D. in mechanical engineering from the University of Nevada Las Vegas. During her studies, she interned at NASA, contributing to criticality assessments for a pulsed fusion engine concept. Kimberly also lent her expertise to the US DOE Nuclear Emergency Support Team's Aerial Measurement System group and engaged in MCNP simulations of radiation detectors. Her dedication to innovation led her to extend her graduate work, showcasing her commitment to advancing technology.

MD Zahid Hasan

Zahid graduated from the University of Bremen, Germany specializing in Material Science of Production Engineering. After graduation, Zahid worked in the Research and Development department of various European aerospace companies, like, FOKKER Aerostructures, The Netherlands, and Composite Technology Centre (Airbus), Germany, for about seven years. During his industrial career, he has developed finite-element and multi-physics-based codes to simulate aerothermodynamic-structure interaction of space vehicles and icing of aircraft. He has also conducted numerous experiments in different lab facilities, e.g., Vienna Tech Arsenal, Austria, and Material Processing Lab, Kaunas, Lithuania, to validate the numerical models he has developed. Currently, he is a Ph.D. student in the Structural Integrity group of Nuclear Futures Institute, Bangor University. His Ph.D. research topic encompasses implementing the phase field method to simulate the damage of nuclear fuels and nuclear structural materials under severe thermo-mechanical loading.

Luis E. Herranz

Luis E. Herranz Ph.D. from the Polytechnique University of Madrid (UPM) in 1996. Research Professor since 2015, he has been leading the Unit for Nuclear Safety Research for more than 20 years. He has published more than 150 papers in refereed journals and has made more than 300 contributions in international conferences and workshops. Since 2019, Luis E. Herranz has been the leader of the Technical Area 2 (Severe Accidents) of SNETP/NUGENIA and was the Chair of the WGAMA (Working Group of Analysis and Management of Accidents) of OECD/NEA between 2016 and 2021. With a strong committed to teaching and training, he regularly lectures in national and international graduate and post-graduate courses.

Dr Matthew Horton

Matthew Horton has completed an integrated masters in theoretical physics at the university of Leeds. Matthew continued on and completed a PhD under the materials engineering department at the university of Sheffield. The PhD focused on creating a Smooth Particle Applied Mechanics (SPAM) model of nuclear fuel and cladding. Matthew went on to join NNL as a chemical and process modeller and has focused on the development of the Magnox Swarf Storage Silos (MSSS) Effluent gPROMS model (MEG). Matthew has also taken on supervision of a student at the nuclear futures centre at university of Bangor doing continued research into the application of SPAM to fragmentation of nuclear fuel. Matthew has attended meetings with the OperaHPC project, under Horizon Europe which the research from Bangor is a part of. He has also taken on supervision of a student at imperial using DFT to examines phases present within nuclear fuel formations. Matthew has extensive experience coding in FORTAN. Matthew also has experience with R, gPROMS, Python, Mathematica and C.

Kostadin N. Ivanov, Ph.D.

DISTINGUISHED PROFESSOR AND DEPARTMENT HEAD
DEPARTMENT OF NUCLEAR ENGINEERING
NORTH CAROLINA STATE UNIVERSITY

- Fellow, American Nuclear Society (ANS)
- Chair, Working Party on Reactors Systems, Nuclear Science Committee, Nuclear Energy Agency (NEA), Organization of Economic Cooperation and Development (OECD)
- Member and former Chair, Executive Committee of Nuclear Engineering Department Head Organization, USA
- Member, Advisory Board of the Nuclear Engineering Program at University of Florida
- Member, Scientific Advisory Committee of Division of Nuclear Energy and Safety at the Paul Scherrer Institute, Switzerland
- General Co-Chair, 2024 Best-Estimate Plus Uncertainty (BEPU-2024) International Conference for Nuclear Power Reactors Safety Assessment and Licensing
- General Co-Chair, ANS Conference on Nuclear Training and Education: A Biennial International Forum (CONTE 2023)

The technical expertise of Prof. Dr. Ivanov is in computational multi-physics multi-scale modeling and simulations for nuclear reactor design evaluations, nuclear power plants safety analyses, and regulatory confirmatory applications.

Prof. Dr. Ivanov has more than 40 years of professional experience in the nuclear power industry, research organizations and academia. He earned his Ph.D. degree in reactor physics from the Bulgarian Academy of Sciences in 1990. Prior to joining North Carolina State University in 2015, he held several research and academic positions in USA (Pennsylvania State University), Germany (Karlsruhe Institute of Technology and Helmholtz-Zentrum Dresden-Rossendorf), and Bulgaria (Institute of Nuclear Research and Nuclear Energy, Technical University of Sofia, and Kozloduy Nuclear Power Plant).

Prof. Dr. Ivanov has published his work in over 310 technical articles in peer-reviewed journals and conference proceedings.

Prof. Dr. Ivanov has graduated 108 Master of Engineering, 63 Master of Science, and 45 PhD students.

Prof. Dr. Ivanov 's teaching activities, over the last 22 years, have been focused on introducing, improving, and teaching undergraduate and graduate courses in nuclear reactor physics analysis, design, and safety, which are keystones of the nuclear engineering education. He has taught in total 100 classes for resident students and forty-three 43 classes for continuing (distance) education.

Prof. Dr. Ivanov has been able to maintain continuous diverse research support from national and international government agencies, national laboratories, industry, consulting companies, and other universities. He has been principal investigator and co-principal investigator for more than 105 externally supported projects totaling approximately $20M of external funding.

Dr. Ivanov has led 15 international programs supported by NEA/OECD, U.S. Nuclear Regulatory Commission, and U.S. Department Of Energy.

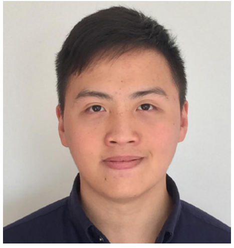
Dr John Jones

Dr Jones is Technical director of Fairlie Associates. Previously he had technical lead responsibilities for the area of fuel and core at the Office for Nuclear Regulation and also for LWR fault analysis at EdF Energy. He was responsible for the analysis to support the first fuel reload at Sizewell B and he taught fluid mechanics at the Royal Naval College, Greenwich. His PhD thesis was on the topic of fuel clad ballooning and he represented UK on a number of related international initiatives including editing the updated draft of the CSNI state-of-the-art report on LOCA; which is due to be published shortly.

Andrew Jung

Andrew Jung is the System Planning Modeling Lead at Savannah River Mission Completion LLC (SRMC), Contractor to the United States Department of Energy. In his 5 years with the Savannah River Liquid Waste Contractor, he has helped develop and maintain modelling and trending capabilities for long term strategic planning. Recently these capabilities have been expanded through collaboration with DBD Limited. Andrew's analysis has been in understanding emergent interfacility dependencies and leading solution development as SRMC accelerates its liquid waste processing. He graduated with a bachelor's degree in chemical engineering from Northwestern University in 2017, and has been expanding his focus on lifecycle modeling and planning through his positions in SRMC. Andrew has previously worked on engineering support for direct facility operations and performing accident analyses.

Jason Lee



Jason Lee is a PhD researcher at the Nuclear Energy Futures CDT at Imperial College London. Trained as a material scientist, his research efforts aim to tackle the underlying mechanisms behind corrosion and bridge the gap between experimental and theoretical understanding. As part of the latest generation of nuclear scientists and engineers, he hopes to one day assist in the application of nuclear as an energy source in his home country of Singapore.

Jason's commitment to further understanding of nuclear related processes has been recognised through a scholarship from the Singapore Nuclear Research and Safety Initiative. His work on microstructural influence on corrosion kinetics was awarded the Charles Salter prize, Imperial College's award for excellence in Metallurgy.

Cintia Leite Gonçalves

PhD student - Bangor University, UK

Research in progress - Model the thermal conductivity (TC) of UN, comparing with experiments and previous results. Understand the role of impurities, stoichiometry, and nuances such as nitrogen enrichment on the TC value; Develop a model giving the effective thermal conductivity of fresh fuel when grain boundaries are coated and UN alloys, coupled with parametric study of the main candidates; Develop a thermal conductivity degradation (TCD) model for UN verifying what are the most important parts: intrinsic defects, fission product accommodation, secondary phases, porosity, etc. Focus will be given to understand the role of the high burnup rim region and understand if a high-burnup or rim structure could impact the overall thermal conductivity performance. Impact of additives on TCD will subsequently be considered (segregation effects etc.).

Master's in chemical engineering - University of Paraná, Brazil
Graduated in Chemistry- Federal Institute of Maranhao, Brazil

Linfeng Li

I am a 2nd year PhD student from the Department of Earth Science and Engineering at Imperial College London supervised by Jiansheng Xiang and Chris Pain. My PhD project is on developing advanced simulation methods for fluid-induced vibration in nuclear engineering. My general research interests include finite element methods and AI modelling. Before joining Imperial in 2020, I got my BEng (2017) and MEng (2020) degrees both from Xi'an Jiaotong University.

Dr Michael McDermott

I obtained a Masters in Theoretical Physics from the University of Leeds, and then pursued a PhD in Mechanical Engineering (CFD) focused on RANS models for turbulent viscoelastic fluids, achieving multiple publications in the field. I have spent time in industry with Procter & Gamble and their R&D team to optimise fabric care manufacturing with thermal analysis and CFD. My current role as a Research Associate at the University of Sheffield is focused on developing a multi-scale modelling framework for printed circuit heat exchangers in service of Gen IV nuclear reactors.

My overall research goal and interest is focused on developing and implementing advanced mathematical models with user-friendly and open-source coding packages to effectively address complex industrial energy challenges.

Dr. Simon Middleburgh

Dr. Simon Middleburgh is a Reader in Nuclear Materials at Bangor University. He was appointed to the Nuclear Futures Institute in March 2018. His research is focused on developing new nuclear materials, investigating material behaviour in extreme environments (including nuclear and aerospace) and combining materials modelling techniques with experimental methods. Simon has over 60 peer reviewed journal articles and 13 patents. He is building a suite of software and hardware capabilities at Bangor University in order to support industrially relevant research in order to produce research in a timely manner required by the nuclear industry.

Simon has had positions at the Australian Nuclear Science and Technology Organisation (ANSTO), Australia as a Research Leader and at Westinghouse Electric Sweden AB as a Senior Engineer where he used his methods to advance fuel development and fuel performance modelling methods.

Simon brings experience from the nuclear industry to Bangor University and has taken part in a number of expert panel groups including within the IAEA. Simon is part of a number of international research collaborations and has been on the nuclear advisory committee at the Centre of Nuclear Engineering at Imperial College London, consulted for the UK Foreign and Commonwealth Office and the UK National Nuclear Laboratory.

Prof Christopher Pain

Prof Christopher Pain (PI and physics lead, ICL) leads the Applied Modelling and Computation Group (AMCG) at ICL. Recipient of the ICL Research Excellence award in 2011 (for high academic achievement and future potential), AMCG is Imperial's largest research group comprising about 60 scientists. He is the director of the data assimilation lab in the Data Science Institute (DSI) at ICL and is co-director of the Centre for AI-Physics Modelling at Imperial-X, leads the modelling for the MEMPHIS (£5M) and MAGIC (£5M) consortia and is PI of Smart-GeoWells (£2M) Newton consortium. Has interests in numerical methods, environmental and engineering fluids (e.g. multi-phase flows, urban flows). He developed the first Large Eddy Simulation air pollution models, the first 3D tetrahedral- based mesh optimisation and conservative mesh-to-mesh interpolation methods; he was the original developer of the FETCH transient criticality model for nuclear systems; he developed the first Non-Intrusive Reduced Order Model (NIROM) for fluid mechanics. >300 journal papers, supervised 60 PhD students, completed 42 industry and research council grants, h index=57

Dr Nathan Palmer

I am a Process Modeller at National Nuclear Laboratory (NNL) and work on a range of projects from modelling plutonium dioxide (PuO2) to solvent extraction modelling. I joined NNL in 2020, following a PhD in atomistic simulations of PuO2 and mixed oxide (MOX) fuel at the University of Birmingham. I have a background in physics, having obtained a master's degree in the physics and technology of nuclear reactors (PTNR) and a bachelor's degree in physics, both from the University of Birmingham. Since 2022, I have been the Knowledge Management Co-ordinator at NNL, where I arrange for speakers to give talks on a range of topics. I have enjoyed attending Nuclear Institute Young Generation Network (YGN) events including nuclear site tours and seminars and I have supported early careers through outreach activities at NNL. I am currently working towards chartership with the Institute of Physics.

Dr Simon Richards

Dr Simon Richards is the Design Authority for the MONK Monte Carlo criticality safety and reactor physics code, and leader of the MONK development team in the ANSWERS Software Service within Jacobs.

He graduated in Physics (BSc, 1991) and Plasma Physics (MPhil, 1994) from Imperial College, London, and spent several years working in nuclear fusion plasma diagnostics at the Joint European Torus (JET) and Imperial College. He then spent over 13 years working as a physicist in the underwater defence industry, gaining a PhD in underwater acoustics from the University of Southampton in 2003. He is a Fellow of the Institute of Physics and a Chartered Physicist.

Simon returned to the nuclear industry in 2008 when he joined the ANSWERS team at Winfrith, and took over the role of lead MONK developer in 2012. In addition to carrying out code developments and leading the development team he also regularly trains new MONK users in the use of the code and in best practice in Monte Carlo criticality safety and reactor physics modelling, and supports users around the world in a wide range of criticality safety and reactor physics applications.

Professor Paul Smith

Paul Smith is the technical director of Jacobs' ANSWERS Software Service. He has worked in mathematical modelling for over 45 years and in the nuclear industry of 38 years. He is also a visiting professor in the Applied Modelling and Computation Group at Imperial College London and in the Nuclear Futures Institute in Bangor University.

Maria Susini

Maria Susini holds a Master's degree in Nuclear and Subnuclear Physics, which laid the foundation for her current research journey as a PhD student at University of Turin. As a a first-time conference presenter, she is excited to share the results obtained during her internship at Newcleo srl. During her time at NewCleo, Maria focused her reserch on an important and relatively unexplored topic: coolant heating in Lead-cooled Fast Reactors (LFRs). Maria's master's thesis represents her initial step into reactor physics research and she is genuinely honored to be a part of this event and is keen to share her perspective with the audience.

Eleftherios Vlazakis

Eleftherios is Applied Statistician (MSc), graduated from AUEB in Greece, with 8 years of working experience in R&D and Supply Chain. He joined NNL as Statistician in National Nuclear Laboratory in 2022 where his focus is mostly on fuel development and decommissioning, supporting the further expansion of customers relying on data driven models.

Prior joining NNL he worked in R&D departments of Unilever and Nestle. There, in collaboration with field experts, he provided guidance for efficient experimentation (DoE) and model-based insights. Eleftherios is keen Statistician, with expertise in a wide range of modelling techniques (frequentist and Bayesian) and interest in building bespoke models to provide insights into unique problems.

Ruben Van Parys

Ruben Van Parys graduated in Physics Engineering at Ghent University in 1999. Currently, he is senior engineer in the core and fuel competence domain of Tractebel and has more than 20 years of experience in neutronics and core thermal-hydraulics for Belgian nuclear power plants Doel and Tihange, performing cycle specific reload safety evaluations, in-core follow-up verifications, loading pattern optimizations, and much more. Ruben has been technical coordinator of the Tractebel review of the ESKOM Koeberg plant safety case for steam generator replacement. Within Engie, he is trainer for nuclear fuel cycle and reactor physics subjects.

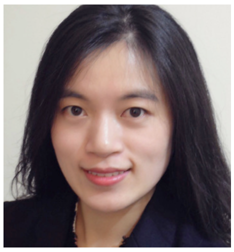
He also participated in several assessments for nuclear new build projects and is acting as a point of contact for SMR designs (molten salt, gas cooled, light water, boiling water, sodium cooled fast reactor) within the core and fuel domain.

Iona Webster

Iona is a Mathematician within the Radiometric Systems Group Characterisation Team at Sellafield Ltd. They joined the company’s graduate scheme in 2021 after studying Mathematics at the University of Warwick. There they specialised in algebra and geometry, writing their dissertation on topological data analysis.

Since joining Sellafield, they have used their data analytics skills across a wide range of projects. Their main area of focus has been on developing reconstruction techniques to determine the locations of radioactivity within highly active vessels, with particular interest in the application of MLEM and SART. They have explored the optimisation of stopping functions for these algorithms and how noise propagates through the problem. Iona is working on expanding these techniques across a wider range of facilities at Sellafield.

Dr Jiejie Wu



Dr Jiejie Wu (read as /jayjay/) is a Lead Mathematical Modelling Consultant in Jacobs, with extensive experience in safety assessment of post-closure, groundwater and coupled thermal-hydro-mechanical (THM) modelling. She has led work on a variety of waste management projects both nationally, for Nuclear Waste Services Ltd (NWS), and internationally, for SKB, Nagra, Posiva and JGC JAPAN.

Jiejie is leading the assessment of radionuclide contamination transport for criticality calculation for the Pu IPT framework which is to dispose UK's plutonium waste. The assessment utilises a Monte Carlo tool, GoldSim, to construct probabilistic models, with dozens of parameters having probability distributions. Jiejie is also leading the development of an automation tool to enhance the efficiency, completeness, and accuracy of criticality assessment. This will strengthen the post-closure criticality safety case increasing confidence in the results.

Jiejie led the modelling work for multiple international projects to develop THM mathematical models of bentonite in high temperature with implementation of a Finite Element Method platform, COMSOL Multiphysics. Jiejie provided key modelling support to the groundwater assessment GoldSim model for initial understanding of the disposal high activity waste in a near surface disposal facility, silos, in LLWR.

Jiejie has extensive experience in using Python for data analysis and visualisation for various projects with key modules NumPy, Pandas, Bokeh, Matplotlib, Seaborn, etc. Jiejie has produced and contributed to various technical reports, first-author publications in journals and conference proceedings, and presented her work in 10+ international conferences, with serval prizes.

Dr Vadim Zolotarevskiy

Dr Zolotarevskiy joined the Nuclear Graphite Research Group at the University of Manchester in 2022, as a Research Associate in graphite material modelling. His research involves performing graphite material brick computational modelling where there are questions from the regulators concerning how the brick changes shape and develops stresses during operation

He received his MSc and PhD degrees from the Faculty of Mechanical Engineering at the Technion – Israel Institute of Technology. During his master's Dr Zolotarevskiy investigated the effect of tangential loading on material response in elastic-plastic spherical contact. His PhD research thesis focused on heat transport in low-dimensional models and mechanisms of energy dissipation leading to normal heat conductivity. After completing the PhD, Dr Zolotarevskiy worked as a postdoctoral fellow in the Faculty of Science and Technology at Bournemouth University in collaboration with SKF Research and Technology Development Centre. His project focused on finite element modelling and analysis of ceramic rolling elements with surface imperfections.

Prior to joining the NGRG Dr Zolotarevskiy held a position of associate Research Fellow at Deakin University (Australia) and conducted a numerical analysis on wear in mineral processing systems. Dr Zolotarevskiy also worked as a simulation software developer in a Knowledge Transfer Partnerships programme between Bournemouth University and BEASY Ltd. His expertise includes modelling with finite and discrete element methods, molecular dynamics simulations as well as FORTRAN programming, with special interest in application of computational mechanics in material science.

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