Keynote talks: Government Policies and Regulations

- **BEIS Thermal hydraulics project, Carolyn Howlett, Fraser-Nash Consultancy**

Speaker Biography:

Carolyn Howlett completed her degree (MEng) at the University of Cambridge in 1997 and started work with Frazer-Nash Consultancy. Over the last 20 years she has worked to solve fluid flow and thermal analysis problems across the civil nuclear, gas turbine, defence and aerospace industries. She currently holds the role of Principal Consultant specialising in the application of thermal hydraulic analysis in a civil nuclear context.

Although the majority of her work has been in the practical application of modelling methods in 'real' engineering environments, she has also retained a keen interest in advancing the state-of-the-art, and has been involved in the development of a number of bespoke modelling tools. For the last 18 months Carolyn has been part of the project team responsible for delivering Phase 1 of the BEIS 'Digital Reactor Design - Thermal Hydraulics' research and development project.

- **A UK Regulatory perspective on "Computational Fluid Dynamics" (CFD) for Nuclear safety analysis Jonathan Downing, John Jones, Ali Tehrani, Office for Nuclear Regulation**

Abstract:

Nuclear safety analysis typically involves the implementation of a thermal hydraulic system code which has been validated against test data. Computational Fluid Dynamics (CFD) has achieved relatively little penetration into nuclear safety cases for licensing purposes; principally due to the need to demonstrate that uncertainties in the analysis have been accounted for to a high level of confidence. This presentation provides a UK regulatory perspective on a number of key CFD topics within the context of nuclear safety analysis.

CFD can sometimes provide a useful role in generalising the lessons learned from tests. CFD can also provide visualisation of phenomena and hence aid in understanding and explaining physical concepts and problems. However, a step increase in the level of confidence is required in moving from these qualitative, illustrative benefits of CFD to nuclear safety analysis where a comparison to an assessment criteria is made with nuclear safety significance.

Speaker Biographies:

Jonathan Downing completed his MEng(hons) with distinction from The University of Leeds. On graduation he was awarded the A. L. Roberts Prize for Fuel and Combustion Science. He worked at Rolls-Royce Nuclear for ten years, rising to the position of Internal Authority for Decay Heat Removal. While at Rolls-Royce he carried out the role of Technical Leader with respect to the formation of the Rolls-Royce Thermofluid Analysis University Technology Centre. Research was conducted at the doctoral level, with the aim of advancing the validation of Computational Fluid Dynamics (CFD) for nuclear safety applications. He is currently a Nuclear Safety Inspector for the Office of Nuclear Regulation, specialising in fault studies, fuel and core.

Dr Jones completed a PhD in the modelling of large-break loss of coolant accidents in 1985, after which he worked as a senior lecturer developing two-phase CFD analysis methods. He moved to CEGB to participate in the design of the Sizewell B power station, where he represented CEGB on the turbulence-modelling working group and participated in the development of a number of analysis methods; including MACE and PANTHER. He managed the analysis for Sizewell B's first reload and developed safety cases for plant modifications. He has been an inspector at NII/ONR for ten years.

Prof. Tehrani completed his MSc from King's College London and PhD from Exeter University covering modelling of nuclear plant performance in accident conditions. He is a principal nuclear safety regulator with Office for Nuclear Regulation with many years experience in the nuclear and highly regulated industries covering new generations of civil and naval nuclear power plants and their supporting test facilities as well as significant contributions to nuclear new build in the UK. He is concerned with the development, verification and validation of analysis methods supporting lumped parameter, Computational Fluid Dynamics and multi-physics codes used in dealing with complex and challenging plant performance characteristics, such as that in severe accident conditions. He has provided regulatory support to the MoD Safety Regulator including Nuclear Licensed site naval bases including supporting the requirements of the naval reactors and numerical modelling techniques. He is also a visiting professor at Imperial College London, with scientific expertise including: predictive best-estimate analysis of nuclear reactor plants and systems, multi-phase flow and Multiphysics computational analysis. He has authored a large number of publications and is a member of the editorial board for scientific journals such as International Journal of Multiphysics.

Session 1: Application of Modelling in Risk Analysis

- **Challenges in developing safety analysis models of the EU tritium breeding modules for the ITER fusion project, Andrew Grief, Wood**

Abstract:

The ITER fusion experiment will offer the chance to test the tritium breeding technologies required to fuel the DEMO reactor and future fusion power stations. This will be accomplished by a number of Test Blanket Modules (TBMs), set into the outer wall of the ITER plasma chamber. The Helium-cooled Lithium Lead (HCLL) TBM design proposed by Fusion for Energy will breed tritium within a slowly flowing molten lithium-lead alloy. The Helium-cooled Pebble Bed (HCPB) TBM design will breed tritium within beds of small lithium and beryllium-containing pebbles. Both designs use a flow of high-pressure helium to cool the breeding material and to manage the very high heat loads on the structure of the TBM. This presentation will describe the challenges associated with developing safety analysis models for these

novel nuclear systems, including 3-d heat transfer modelling, simulating chemical reactions and representing magneto-hydrodynamic effects. The steps taken to address these challenges using the MELCOR and RELAP5 codes will be outlined.

Speaker Biography:

Dr Andrew Grief joined Wood (formerly Amec) as a consultant specialising in thermal-hydraulic analysis and computational fluid dynamics in 2005. His work has included the development of new reactor thermal-hydraulics tools and safety analysis models for a range of advanced fission reactors, including the PBMR and prismatic high-temperature gas reactors and fusion technologies, together with providing support to the UK reactor fleet and new build programmes.

- **Virtual Engineering in Nuclear Reactor Applications, John Lillington, Wood**

Abstract:

Virtual engineering provides multi-faceted links between collaborating engineering teams through the development of computer models and other tools within a multi-disciplinary environment. It is becoming ever more practical through the increasing availability of High Performance Computers (HPCs) and also strides in effective 'big data' management. It is already extensively used in some industries e.g. aerospace; its use is now growing within the nuclear industry, the subject of this presentation.

The presentation will provide some examples of developments in progress from experience gained from the UK BEIS supported nuclear virtual engineering project, which covers integration of different design steps / data transfer, code coupling, multi-physics etc. in the context of a representative UK nuclear industry study. The methodology can be applied to design development but also for normal operational support and fault studies analysis in risk assessments. The presentation will cover the overall simulation framework, how the integrated nuclear digital environment works and the benefits it can provide. This will be by reference to several different applications. The presentation will also refer briefly to some international activities in this field.

Speaker Biography:

Dr John Lillington has worked for more than 40 years within the UK Nuclear Industry with the United Kingdom Atomic Energy Authority (UKAEA), its privatised sector, AEA Technology, Serco, Amec Foster Wheeler and most recently Wood. He originally graduated in mathematics from the University of London (BSc, PhD) and is a Fellow of the Institutes of Physics and Mathematics (FInstP, FIMA) and a Chartered Engineer (CEng). During his career, he has worked on all the major reactor systems (water, gas and fast reactor) as a specialist in thermal-hydraulics, theoretical physicist, safety analyst, technical programme, resource and project manager. He is currently Chief Technologist, Nuclear Reactors within Wood. He is a part-time lecturer and examiner at several UK universities and has published two books and numerous articles on nuclear power related subjects. John was appointed as a member of the first UK Nuclear Innovation and Research Advisory Board (NIRAB) to advise on R&D to underpin the UK Government's vision for future nuclear energy. He is an UK representative on the European FORATOM R & D Task Group.

- **Development and Application of Risk Oriented Accident Analysis Methodology for Nordic BWR Severe Accident Management Strategy,** **Sergey Galushin, Dmitry Grishchenko, Pavel Kudinov, KTH, Sweden**

Abstract:

Risk Oriented Accident Analysis Methodology (ROAAM) was originally developed for assessment of rare, high-consequence events, where both aleatory (stochastic) and epistemic (modeling) uncertainties play a significant role in the risk assessment. The main purpose of ROAAM is to provide the input material to an underlying decision problem, and enable robust decision making regarding current safety design and procedures and possible design modifications. Further development of ROAAM+ employs (i) comprehensive sensitivity analysis and uncertainty quantification methods, (ii) surrogate modeling approaches.

In this work we present the current status of ROAAM+ framework development. We discuss an example of ROAAM+ application to Nordic type BWR, considering the issue of ex-vessel steam explosion. We use sensitivity analysis to identify the most influential parameters for every stage of accident progression, and we quantify the effect of these parameters and the effect of possible design modifications on the probability of failure and associated uncertainty, using failure domain analysis approach. The results of the analysis are presented in form of distributions of failure probability and evaluated according to relative safety significance criteria.

Speaker Biography:

Presenter is Sergey Galushin, PhD student at the Division of Nuclear Engineering, KTH, Stockholm.

Session 2: Data Assimilation and Uncertainty

- **Selective application of the method of Propagation of Uncertainty to determine Safety Margins to a High Level of Confidence.** **Edmund Jones, Imperial College London**

Abstract:

It is common practice in high hazard industries to determine the upper limit of a safety parameter by employing a deterministic model of a safety system, together with a postulated set of probability distributions for uncertain input parameters. A process often employed is to randomly sample the probability distribution of the safety parameter of interest by sampling the postulated distributions of the uncertain input parameters and repeatedly applying the deterministic model for each derived set of input data. The process is repeated until the desired level of probability is enveloped at a desired confidence level. The process is often referred to as propagation of uncertainty and can be effort and resource consuming if the deterministic model is complex.

This paper proposes that the process can be optimised by recognising that only a limited number of sampled input data sets are likely to provide information relevant to determining the upper limit of the parameter of interest and therefore only a relatively small number of sets of data require application of the deterministic model.

The approach outlined in this paper recognises that, in sampling the model input parameter distributions, information becomes available about the probability of each sampled point because the component probability distributions are pre-determined. It follows that a criterion can be developed to exclude some points from the deterministic evaluation of the system response without significantly affecting the objective of enveloping the expected safety system response with a high level of confidence.

An example of the method is used to illustrate consideration of an accident in a pressurised-water reactor.

Speaker Biography:

Edmund Jones is studying in Mechanical Engineering at Imperial College London. Prior to this, he worked for Sharp Europe. He led a small design team and development image analysis and LED-modulation software for image enhancement. He oversaw the process qualification and transfer to mass-production of new high-power LED displays for use outdoors. His work was nominated for an award under the EDT future industry leaders scheme.

- Data Assimilation Techniques applied to Reactor Analysis, Jonathan Dixon, **University of Cambridge**

Abstract:

Many challenges remain in the Best Estimate Plus Uncertainty methodologies including dimensionality reduction of the uncertainty space, predictive confidence beyond the current range of validation experiments and accounting for wider model discrepancies. Research at Cambridge University is focused on combing uncertainty quantification and data assimilation techniques applied to reactivity-initiated accident scenarios with a focus on UK reactors and areas with less experience in best estimate plus uncertainty. Research has so far focused on comparing different methodologies and applying to a PWR rod ejection accident using WIMS-PANTHER.

Speaker Biography:

Based at Gonville & Caius College, Cambridge where I have recently started the second year of my PhD. I have also completed degrees at Imperial College London and Lancaster University. My interests in nuclear stem from being a member of a local liaison group at Heysham nuclear power plant during my undergraduate Physics degree. I worked in industry for a short while producing graphene and controlling plasma reactors before returning to academia to undertake research in uncertainty quantification applied to reactor analysis.

- Higher-Order Predictive Modeling of Coupled Multiphysics Systems with Applications in Nuclear Science and Engineering, Dan Cacuci, **Bangor University**

Abstract:

The author has recently developed the "predictive modeling of coupled multiphysics systems" (PM-CMPS) methodology, which encompasses the following intertwined scientific fields: (i) sensitivity analysis; (ii) uncertainty quantification; (iii) data assimilation; (iv) model validation; (v) model calibration; (vi) obtaining best-estimate predicted results with reduced predicted uncertainties. Applications of the PM-CMPS methodology for obtaining best-estimate results with reduced uncertainties will be illustrated for several large-scale systems, including: (1) a full reactor core OECD/NEA benchmark; (2) void fraction analysis for a full-scale BWR assembly tested in Japan's NUPEC BMBF facility; (3) Savannah River National Laboratory's F-Area cooling towers; and (4) inverse nuclear material thickness prediction. Ongoing

extensions aimed at incorporating into the PM-CMPS second (and subsequently higher) order sensitivities computed using the author's recently developed paradigm-shifting "2nd-Order Comprehensive Adjoint Sensitivity Analysis Methodology" (2nd-CASAM), will also be presented.

Speaker Biography:

Professor Cacuci's career spans over 40 years in the field of nuclear science and energy, encompassing both academia and large-scale multidisciplinary research centers. He currently serves as the Ser Cymru Distinguished Professor of Predictive Modeling and Nuclear Engineering at Bangor University. He has received 3 graduate degrees, including his PhD (1978), from Columbia University in the City of New York. His scientific expertise includes the following areas: predictive best-estimate analysis of large-scale physical and engineering systems, large scale scientific computations, nuclear science and engineering (reactor multi-physics, dynamics, and safety).

Since 1984, Prof. Cacuci has been the Editor of Nuclear Science and Engineering –The Research Journal of the American Nuclear Society (ANS). He has received many prestigious awards, including four titles of Doctor Honoris Causa, the E. O. Lawrence Award and Gold Medal (from President Clinton, USA, 1998), major awards bestowed by the American Nuclear Society including the Arthur Holly Compton Award (2011), the Eugene P. Wigner Award (ANS, 2003), the Glenn Seaborg Medal (ANS, 2002), Young Members Engineering Achievement Award, (1988), ANS Fellow (1986), and Germany's Alexander von Humboldt Prize for Senior Scholars (1990). He is a member of several international and national academies of arts and sciences, has made over 600 presentations worldwide, has authored 6 books, 7 book chapters, over 250 peer-reviewed articles, and has edited the comprehensive Handbook of Nuclear Engineering (5 volumes, 29 chapters, 3580 pages, Springer, 2010).

Session 3: Validation and Verification

- **Paul Bryce, EDF Energy, Reactor core analysis: Past and Future**

Abstract:

Current industrial tools used for reactor core modelling and analysis utilise multiple linked simulation techniques in areas such as neutron transport, thermal-hydraulics and heat transfer, isotopic transmutation and mechanical performance. Over many years approximations, tabulations and separations have been carefully applied and validated to permit problems to be solved to a high degree of accuracy at a relatively modest computation cost.

Advances in computational speed, memory and storage permit (for example) the tens to hundreds-of-thousands of calculations to design and check the key safety parameters of a PWR reactor core to be performed in a few hours on an off-the-shelf laptop. These same advances also offer the possibility of returning to the tools to increase their fidelity, remove approximations and simplifications and integrate models together, and several projects in this area are in progress worldwide.

These higher fidelity models come with prospective benefits (for example in accuracy, reliability, user skills and cost), but they also come with additional difficulties (often in the same areas). Some of these issues will be examined with reference to examples from UK industry and international programmes.

Speaker Biography:

Paul Bryce started work for Nuclear Electric in 1991 and has worked for its successor companies British Energy and most recently EDF Energy. Over that period, he has worked in the Reactor Physics area, developing and applying computer models to monitor, study, license and operate the UK's water-cooled and gas-cooled reactors.

- Verification and validation of ANSWERS software, Paul Smith, **Wood**

Abstract:

ANSWERS software is developed to ISo 9001 standard in line with ANSWERS and company procedures. The software development follows an agile lifecycle with tasks specified and monitored in the Jira issue-tracking system and carried out using either scrum process or Kanban boards. In either case developments involve code modifications, testing and documentation and each phase must be independently reviewed before a task can be designated complete. Software, including documentation is held in a subversion repository which is monitored by BuildBot. When a commit is made to the repository BuildBot builds the codes that use the affected modules and launches our in-house auto-test-tool to launch the appropriate tests for the affected codes. Code testing involves unit and integration tests in addition to the use of three different compilers on two different platforms with warning messages used to identify potential errors in the code. Data assimilation methods are used to combine measured data and calculated results to provide the best estimate for the application case and the associated uncertainty. This provides a systematic way to use the available measured data to evaluate and remove code bias and estimate uncertainty.

Speaker Biography:

Prof Paul Smith has 35 years experience in the nuclear industry and over 40 years experience of mathematical modelling. Paul is Technical Lead for Modelling and Software in Wood and is manager of the ANSWERS® Software Service. His career in the nuclear industry began with work in support of the severe accident safety case for the Sizewll B nuclear power station. He went on to lead a programme of theoretical (Winfrith) and experimental (Harwell and Risley) phenomenological investigations to support the development of Severe Accident Management Guidelines for the AGR and Magnox reactors. He then worked on atmospheric dispersal of radioactive materials followed by the development of models to improve understanding of hypothetical post-closure criticality in geological disposal facilities, before becoming ANSWERS manager. For over a decade he has been a visiting professor in the Applied Modelling and Computation Group (AMCG) at Imperial College London in the areas of radiation transport modelling and multi-phase flows.

- Material Transport in Water Cooled Reactor Systems and Formation of Fuel Clad Crud, Jim Henshaw **NNL**

Abstract:

The talk will cover the process of corrosion product formation, transport and deposition in Pressurised Water Cooled Reactors and the mechanism of fuel clad deposit (CRUD) formation. It will discuss how chemistry and thermal hydraulics are coupled for this problem. The talk will cover what we understand,

but also what we don’t understand about this problem and what work is ongoing to resolve some of the issues.

Speaker Biography:

Joined Harwell laboratory in 1987 after a PhD + Postdoc at Cambridge University in Theoretical Chemistry and have been working on nuclear reactor (PWR, BWR, AGR) chemistry topics since then. Currently based at Culham Science Centre employed by NNL.