Nuclear Safety
NEA/CSNI/R(2024)1
July 2026
www.oecd-nea.org

Experimental Validation and Application of CFD and CMFD Codes to Nuclear Reactor Safety Issues (CFD4NRS-9)

Workshop Proceedings
Texas A&M University
20–22 February 2023

OECD
BETTER POLICIES FOR BETTER LIVES

NEA
NUCLEAR ENERGY AGENCY

Nuclear Energy Agency

NEA/CSNI/R(2024)1

Unclassified

English text only

22 July 2026

NUCLEAR ENERGY AGENCY
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

Experimental Validation and Application of CFD and CMFD Codes to Nuclear Reactor Safety Issues (CFD4NRS-9)

Workshop Proceedings

Texas A&M University, 20-22 February 2023

JT03590894

This document, as well as any data and map included herein, are without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

The OECD is a unique forum where the governments of 38 democracies work together to address the economic, social and environmental challenges of globalisation. The OECD is also at the forefront of efforts to understand and to help governments respond to new developments and concerns, such as corporate governance, the information economy and the challenges of an ageing population. The Organisation provides a setting where governments can compare policy experiences, seek answers to common problems, identify good practice and work to co-ordinate domestic and international policies.

The OECD member countries are: Australia, Austria, Belgium, Canada, Chile, Colombia, Costa Rica, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Latvia, Lithuania, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Türkiye, the United Kingdom and the United States. The European Commission takes part in the work of the OECD.

OECD Publishing disseminates widely the results of the Organisation's statistics gathering and research on economic, social and environmental issues, as well as the conventions, guidelines and standards agreed by its members.

NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1 February 1958. Current NEA membership consists of 34 countries: Argentina, Australia, Austria, Belgium, Bulgaria, Canada, Czechia, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, the Netherlands, Norway, Poland, Portugal, Romania, Russia (suspended), the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Türkiye, the United Kingdom and the United States. The European Commission and the International Atomic Energy Agency also take part in the work of the Agency.

The mission of the NEA is:

- to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes;
- to provide authoritative assessments and to forge common understandings on key issues, as input to government decisions on nuclear energy policy and to broader OECD policy analyses in areas such as energy and sustainable development.

Specific areas of competence of the NEA include the safety and regulation of nuclear activities, radioactive waste management and decommissioning, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information. The NEA Data Bank provides nuclear data and computer program services for participating countries.

This document, as well as any data and map included herein, are without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

Corrigenda to OECD publications may be found online at: www.oecd.org/about/publishing/corrigenda.htm.

Please cite this report as:

NEA (2026), "Experimental Validation and Application of CFD and CMFD Codes to Nuclear Reactor Safety Issues (CFD4NRS-9): Workshop Proceedings", OECD Publishing, Paris, https://doi.org/10.82155/nzxe-nk92.

© OECD 2026

Attribution 4.0 International (CC BY 4.0).

This work is made available under the Creative Commons Attribution 4.0 International licence. By using this work, you accept to be bound by the terms of this licence (https://creativecommons.org/licenses/by/4.0).

Attribution – you must cite the work.

Translations – you must cite the original work, identify changes to the original and add the following text: *In the event of any discrepancy between the original work and the translation, only the text of original work should be considered valid.*

Adaptations – you must cite the original work and add the following text: *This is an adaptation of an original work by the OECD. The opinions expressed and arguments employed in this adaptation should not be reported as representing the official views of the OECD or of its Member countries.*

Third-party material – the licence does not apply to third-party material in the work. If using such material, you are responsible for obtaining permission from the third party and for any claims of infringement.

You must not use the OECD logo, visual identity or cover image without express permission or suggest the OECD endorses your use of the work.

Any dispute arising under this licence shall be settled by arbitration in accordance with the Permanent Court of Arbitration (PCA) Arbitration Rules 2012. The seat of arbitration shall be Paris (France). The number of arbitrators shall be one.

COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS (CSNI)

The Committee on the Safety of Nuclear Installations (CSNI) addresses Nuclear Energy Agency (NEA) programmes and activities that support maintaining and advancing the scientific and technical knowledge base of the safety of nuclear installations.

The Committee constitutes a forum for the exchange of technical information and for collaboration between organisations, which can contribute, from their respective backgrounds in research, development and engineering, to its activities. It has regard to the exchange of information between member countries and safety R&D programmes of various sizes in order to keep all member countries involved in and abreast of developments in technical safety matters.

The Committee reviews the state of knowledge on important topics of nuclear safety science and techniques and of safety assessments, and ensures that operating experience is appropriately accounted for in its activities. It initiates and conducts programmes identified by these reviews and assessments in order to confirm safety, overcome discrepancies, develop improvements and reach consensus on technical issues of common interest. It promotes the co-ordination of work in different member countries that serve to maintain and enhance competence in nuclear safety matters, including the establishment of joint undertakings (e.g. joint research and data projects), and assists in the feedback of the results to participating organisations. The Committee ensures that valuable end-products of the technical reviews and analyses are provided to members in a timely manner, and made publicly available when appropriate, to support broader nuclear safety.

The Committee focuses primarily on the safety aspects of existing power reactors, other nuclear installations and new power reactors; it also considers the safety implications of scientific and technical developments of future reactor technologies and designs. Further, the scope for the Committee includes human and organisational research activities and technical developments that affect nuclear safety.

Acknowledgements

The members of the Nuclear Energy Agency (NEA) Committee on the Safety of Nuclear Installations (CSNI) and of the Working Group on the Analysis and Management of Accidents (WGAMA) acknowledge the significant contributions of those individuals who had a key role in the preparation of this summary report, and those who had a leadership role in conducting the CFD4NRS-9 workshop, such as the hosting organisation (Texas A&M University), Yassin Hassan of Texas A&M University and Martina Adorni from the NEA. Additional thanks are extended to Kevin Fernandez-Cosials from Texas A&M University/Universidad Politécnica de Madrid (UPM), in support of the local organisation of the workshop and the preparation of this summary. Final appreciation goes to the organising committee, the scientific committee and the local committee.

Main author of the summary report

Kevin FERNANDEZ-COSIALS, Texas A&M University/UPM

General chairs

Yassin HASSAN, Texas A&M University, United States

Raymond FURSTENAU, Nuclear Regulatory Commission (NRC), United States

Organising committee

Martina ADORNI, NEA

Emilio BAGLIETTO, MIT, United States

Steve BAJOREK, NRC, United States

Chris BOYD, NRC, United States

Kevin FERNANDEZ-COSIALS, Texas A&M University/UPM, United States/Spain

Philippe FREYDIER, EDF (Electricité de France), France

Stephan KELM, FZJ (Forschungszentrum Jülich GmbH), Germany

Elia MERZARI, Penn State University (PSU), United States

Pierre RUYER, Institut de radioprotection et de sûreté nucléaire (IRSN), France

Mingjun WANG, Xi'an Jiaotong University (XJTU), China

Ghani ZIGH, NRC, United States

Scientific committee

Satoshi ABE, Nuclear Regulatory Authority (NRA), Japan

Henryk ANGLART, KTH (Royal Institute of Technology), Sweden

Emilio BAGLIETTO, MIT (Massachusetts Institute of Technology), United States

Sofiane BENHALADOUCHE, EDF, France

Dominique BESTION, former CEA, France

Ulrich BIEDER, CEA (Commissariat à l'énergie atomique et aux énergies alternatives), France

Guillaume BOIS, CEA, France

Francesco DAURIA, University of Pisa (UNIPI), Italy

Abdel DEHBI, Paul Scherrer Institute (PSI), Switzerland

Milorad DZODZO, Westinghouse, United States

Kevin FERNANDEZ-COSIALS, Texas A&M University/UPM, United States/Spain

Philippe FREYDIER, EDF, France

Yassin HASSAN, Texas A&M University, United States

Thomas HOEHNE, HZDR (Helmholtz-Zentrum Dresden-Rossendorf), Germany

Richard HOWARD, EDF, France

Yanping HUANG, NPIC (Nuclear Power Institute of China), China

Brian JACKSON, Kairos Power, United States

Gonzalo JIMENEZ, UPM, Spain

Joshua KAIZIER, NRC, United States

Stephan KELM, IEK (Institute of Energy and Climate Research), Germany

Ed KOMEN, NRG (Nuclear Research and Consultancy Group), Netherlands

Pavel KUDINOV, KTH, Sweden

Jéróme M. LAVIEVILLE, EDF, France

Dr Dirk LUCAS, HZDR, Germany

Graham MACPHERSON, Frazer-Nash Consultancy Ltd (FNC), United Kingdom

Stéphane MIMOUNI, EDF, France

Fabio MORETTI, Newcleo, Italy

Domenico PALADINO, PSI, Switzerland

Victor PETROY, ETH (Zürich Eidgenössische Technische Hochschule Zürich), Switzerland

Maria-Giovanna RODIO, CEA, France

Véronique ROIG, IMFT (Institut de Mécanique des Fluides de Toulouse), France

Pierre RUYER, IRSN, France

Afaque SHAMS, KFUPM (King Fahd University of Petroleum and Minerals), Saudi Arabia

Jan-Patrice SIMONEAU, EDF, France

Chris STANEK, Los Alamos National Laboratory **(**LANL), United States

Gerhard STRYDOM, Idaho National Laboratory (INL), United States

Wenxi TIAN, XJTU, China

Mingjun WANG, XJTU, China

Jinbiao XIONG, SJTU (Shanghai Jiao Tong University), China

Local organising committee (Texas A&M University, United States)

Yassin HASSAN

Kevin FERNANDEZ-COSIALS

Laurie MCARTHUR

Kristine DONATELLO

Steven DOUGLAS BEGNAUD

All figures and tables that do not include source information were created for the activity. The source in these cases is “NEA data, 2023”.

This report was approved by the CSNI at its 74th meeting on 5-6 December 2023.

Table of contents

List of abbreviations and acronyms **8**

Executive summary **11**

1. Introduction **13**

1.1. Workshop objectives 13
1.2. Organisational aspects 13

2. Summary of the workshop sessions **14**

2.1. Keynote Session: 1 14
2.2. Technical Session 1 15
2.3. Technical Session 2 16
2.4. Panel Session 1 16
2.5. Technical Session 3 16
2.6. Technical Session 4 17
2.7. Technical Session 5 17
2.8. Technical Session 6 18
2.9. Keynote Session 2 19
2.10. Panel Session 2 19
2.11. Technical Session 7 20
2.12. Technical Session 8 20
2.13. Keynote Session 3 20
2.14. Technical Session 9 21
2.15. Technical Session 10 22

3. Conclusion and recommendation **23**

Appendix A: List of participants **24**

Appendix B: Technical Sessions Detailed Schedule **28**

List of abbreviations and acronyms

ADS	Automatic depressurisation system
AIAD	Algebraic interfacial area density
ANL	Argonne National Laboratory (United States)
ASME	American Society of Mechanical Engineers
AULA	Abwaschmodell für unlösliche Aerosole (wash-off model for aerosols)
BIT	Bubble-induced turbulence
BPGs	Best practice guidelines
BWR	Boiling water reactor
CEA	Commissariat à l'énergie atomique et aux énergies alternatives (France)
CFD	Computational fluid dynamics
CFX	Computational fluid dynamix (commercial software)
CHF	Critical heat flux
CIAE	China Institute of Atomic Energy
CMFD	Computational multi-fluid dynamics
CNRA	Committee on Nuclear Regulatory Activities (NEA)
CSNI	Committee on the Safety of Nuclear Installations (NEA)
DNB	Departure from nucleate boiling
DNS	Direct numerical simulation
EDF	Electricité de France
ETH	Zürich Eidgenössische Technische Hochschule Zürich
FCVS	Filtered containment venting system
FIV	Flow-induced vibration
Fluent	Commercial multi-purpose CFD package by ANSYS Inc.
FoM	Figure of merit
FSIFOAM	Finite volume fluid structure interaction solver based on partitioned approach
FZJ	Forschungszentrum Jülich GmbH
GENTOP	Generalised two-phase flow
HF	Hot functional testing
HTC	Heat transfer coefficient
HZDR	Helmholtz-Zentrum Dresden-Rossendorf (Germany)

IAEA	International Atomic Energy Agency
ICC	Ice condenser containment
IEK	Institute of Energy and Climate Research (Germany)
IRSN	Institut de radioprotection et de sûreté nucléaire (France)
IRWST	In-Containment refuelling water storage tank
JAEA	Japan Atomic Energy Agency
JSI	Jožef Stefan Institute (Slovenia)
KAERI	Korea Atomic Energy Research Institute
KIT	Karlsruhe Institute of Technology (Germany)
LBE	Lead-bismuth eutectic
LDV	Laser-Doppler velocimetry
LES	Large eddy simulation
LIF	Laser-induced fluorescence
LIM	Large interface model
LOCA	Loss-of-coolant accident
LOFT	Loss-of-flow transient
LWR	Light water reactor
MIT	Massachusetts Institute of Technology (United States)
NCSU	North Carolina State University
NCNR	Narodowe Centrum Badan Jadrowych
NEA	Nuclear Energy Agency
NED	*Nuclear Engineering and Design* (Elsevier journal)
NEPTUNE-CFD	French multiphase CFD code
NINE	Nuclear and Industrial Engineering (Italy)
NPIC	Nuclear Power Institute of China
NRS	Nuclear reactor safety
NSC	Nuclear and Radiation Safety Centre (China)
ONL	Oak Ridge National Laboratory (United States)
OpenFOAM	Open-source field operation and manipulation
PANS	Partially averaged Navier-Stokes
PAR	Passive autocatalytic recombiner
PFM	Pressure fluctuation model
PGSFR	Prototype Gen-IV sodium-cooled fast reactor
PIV	Particle image velocimetry
PSI	Paul Scherrer Institute (Switzerland)

PTS	Pressurised thermal shock
PWR	Pressurised water reactor
RANS	Reynolds-averaged Navier-Stokes
RPV	Reactor pressure vessel
SA	Severe accident
SBLOCA	Small break loss-of-coolant accident
SETCOM	Separate effect test for condensation modelling
SJTU	Shanghai Jiao Tong University (China)
THAI	Thermal-hydraulics, hydrogen, aerosols and iodine
TIV	Turbulent induced vibration
TUNN	Technical University of Nishny Novgorod (Russia)
UPTF	Upper plenum test facility
UT	University of Tokyo (Japan)
UQ	Uncertainty quantification
URANS	Unsteady Reynolds-averaged Navier-Stokes
US NRC	United States Nuclear Regulatory Commission
V&V	Verification and validation
VOF	Volume-of-fluid
WGAMA	Working Group on the Analysis and Management of Accidents (NEA)
XJTU	Xi'an Jiaotong University (China)

Executive summary

The ninth edition of the CFD4NRS workshop, organised under the auspices of the NEA Working Group on Analysis and Management of Accidents (WGAMA), was hosted by the Centre for Advanced Small Modular and Microreactors (CASMR) of the Texas A&M University on 20-22 February 2023 in College Station, Texas, United States. After nearly being cancelled because of restrictions related to the COVID-19 pandemic, the event took place in an in-person format. The workshop brought together international nuclear safety research organisations, technical support organisations, industry and academia to exchange and share experiences and research results related to the development, assessment and application of single-phase and multiphase simulation tools acting on a small scale for nuclear reactor safety (NRS) issues, and to address both CFD applications and the related experimental and instrumentation issues.

The workshop featured 3 keynote lectures, 2 panel sessions and 50 oral presentations. The keynotes and panel sessions were designed in a way that permitted interactions between the audience and the speakers, giving extra time for Q&A, making live polls or directly asking questions to the audience during the sessions. Sixty participants attended the workshop, which focused on offering exposure to state-of-the-art CFD applications and moving forward in the penetration of CFD within the industry and regulatory authorities.

Some key outcomes emerged from the workshop:

- The first and most obvious feedback was the unanimous preference for in-person workshops and events compared to online or hybrid activities because of the large difference in discussions developed and benefits associated from face-to-face interactions. A few presentations were delivered in the form of a video, and even though they helped present some participants who could not attend in person, the solution was not viewed as optimal.
- Regarding the inclusion of CFD as a useful tool for industry and regulators, it was determined that there is a need for more discussions to try to reach consensus on views expressed about the necessity of “minimum standards” in contrast to “best practice guidelines” for CFD. Some participants noted that CFD BPGs are too complex and resource-demanding to become a staple in a CFD-oriented nuclear reactor industry and that other simpler methods could be developed. In this regard, the recommendation to potentially boost the utilisation of CFD for nuclear applications was to create spaces to develop debate and conversations on the topic of assessment and qualification of corresponding tools in order to find a proper solution for both the applicant and the regulator.
- This was in line with another insight, which was that there should be a push to expand the use of open-source codes beyond academia and research institutions, where they are currently mainstream. Many of the contributions from the participants were developed using open-source codes (OpenFoam, Nek5 000, Saturn) and a specific session on the topic was used to assess their current impact. Some benefits associated with using open-source codes were identified during the workshop, but a common collaboration is deemed necessary for a transition from commercial to open-source to happen. Nevertheless, it must be noted that most of the audience was developing careers in research centres or in academia, which could bias this unanimous opinion, so further conversation is needed, especially with stakeholders from industry and regulatory bodies.

- Finally, the workshop also indicated that there is still discussion, and to a certain degree disagreement, on the adequacy of numerical models, schemes or closure equations to replicate specific phenomena with different fluids or conditions. These discrepancies cannot be solved by using one code instead of another but by adequately selecting or creating the proper models and methods within each code; and by coupling experimental work with numerical results, which should still be part of the collaborative effort to expand confidence in CFDs. The recommendation would be to keep expanding the range of the verification and validation of the CFD codes.

1. Introduction

This workshop, part of a biennial series of events sponsored by the NEA and International Atomic Energy Agency (IAEA) that began in Garching (Germany) in 2006, follows the format and objectives of its predecessors in creating a forum wherein numerical analysts and experimentalists can exchange information on the application of computational fluid dynamics (CFD) to nuclear power plant safety and future design issues. CFD resolves a higher level of phenomenological detail compared to the established system-scale tools. While this appears promising, it also raises new questions about how to evaluate and integrate CFD-based safety studies, which are currently limited to a relatively small number of applications. The emphasis of this workshop was not only on offering exposure to state-of-the-art (single-phase and multiphase) CFD applications reflecting topical issues arising in nuclear power plant design and safety, but also on promoting the release of high-resolution experimental data to continue the CFD validation process in this application area.

1.1. Workshop objectives

One of the main goals of the workshop was to discuss and assess the capabilities of open-source CFD. This was deemed interesting as open-source codes have known tremendous development in recent years, with a growing community of users, and have become a staple in some research institutions and national laboratories. There is currently a wide variety of open-source CFD codes being developed, and each appears to present certain advantages as well as some drawbacks. For this reason, a discussion within the CFD nuclear community was expected in this workshop.

Another topic discussed during the workshop was the confidence that CFD brings to industry or regulatory bodies. Since the workshop series started in 2006, the CFD community has grown significantly. Nevertheless, it was unclear whether this had led to an increase or decrease of confidence in CFD results. Is the sector facing the same confidence issues that were discussed at the CFD4NRS of 2006? These were questions that needed an answer, and the workshop was expected to shed some light on the subject.

1.2. Organisational aspects

There were around 60 registered attendees at the CFD4NRS-9 workshop, which was almost half of the level of participation as for the previous workshops. The number of abstracts received following the initial announcements was also around 60, in line with previous workshops in the series. Despite several challenges related to the restrictions caused by the COVID-19 pandemic, the event took place in a in-person format. Additionally, some participants had their visa to enter the United States denied; for this reason, they were invited to participate by submitting a video that was played during the technical sessions. Finally, participants submitted abstracts, which were collected in a book and made available in PDF format; and around 20 participants agreed to share with all participants the slides used for their presentations.

2. Summary of the workshop sessions

The summary of the workshop sessions was drafted from the chairs' comments and feedback about the session. It summarises the main insights, lessons learnt and recommendations that arose during the session. The specific presentations exposed in each technical session can be found in Appendix B: Technical Sessions Detailed Schedule.

The workshop agenda can be seen in Table 2.1. On 22 February, the participants were invited to attend the ASME-CARD-2023 meeting, which took place at the same location.

Table 2.1. Detailed schedule of the CFD4NRS-9

	Monday, February 20		Tuesday, February 21	
Time	Room A	Room B	Room A	Room B
8:45 AM				
9:00 AM	Openning Session		Keynote Session 2	
9:30 AM	Keynote Session 1		Panel Session 2	
10:00 AM				
10:15 AM	Break		Break	
10:30 AM	Technical Session 1 - Computational Methods	Technical Session 2 - Bubble Dynamics	Technical Session 7 - Fuel-fluid interactions	Technical Session 8 - Verification and Validation
11:00 AM				
11:30 AM				
12:00 PM	Lunch		Lunch	
12:45 PM				
1:00 PM	Panel Session 1		Keynote Session 3	
1:30 PM				
2:00 PM	Technical Session 3 - Aerosol and Fission Products Transport	Technical Session 4 - Two-phase Flow	Technical Session 9 - Verification and Validation I	Technical Session 10 - Severe Accidets
2:30 PM				
3:00 PM				
3:30 PM	Break		Break	
3:45 PM	Technical Session 5 - Numerical Studies	Technical Session - 6 Liquid Metals	Closing Ceremony	
4:00 PM				
4:30 PM			Lab Tour	
5:00 PM				
5:30 PM				
5:45 PM			Closing Reception	
6:00 PM	Reception			
6:45 PM				
7:00 PM				

2.1. Keynote Session: 1

2.1.1. Name of the session

Status and directions of CFD applications to containment phenomenology

Session Chair:

Kevin Fernandez-Cosials (Texas A&M University/UPM)

2.1.2. Summary of the session

Analysis of containment phenomena has always been a challenging field for CFD, where trade-offs between accuracy and detail for computational costs are the norm. Additionally, the phenomena that can be developed in a nuclear containment during an accident are

varied and complex, and normally dedicated codes are used for each specific phenomenon, CFD being a complement of system codes. In this context, Stephan Kelm presented the recent advances made in the development of containment FOAM code, an open-source effort to include the most relevant phenomena inside a single code.

The main conclusions from this session are that the tools used have reached a certain maturity that makes it possible to provide quantitative insights in safety studies. Nevertheless, the computational cost still limits the extent of the analysis and the consideration of fundamental best practice guidelines. Also, the benchmark exercises reveal that containment CFD modelling is converging to a kind of agreed mode set for atmosphere mixing but not so in mitigation/safety systems, combustion or numerical approaches.

The steps forward appear to be oriented to gain performance and demonstrative integration in the analysis chain, and to reassess the model basis of two-phase effects, condensation and system coupling. It appears that containment CFD modelling is slowly being taken seriously and, with the current push, the next years will see an increase in use and publications in the field.

2.2. Technical Session 1

2.2.1. Name of the session

Computational methods

2.2.2. Session chairs

Stephan Kelm (FZJ), Chaï Koren (EDF)

2.2.3. Summary of the session

- The session comprised five papers, three of them presented in person and two by video recording. Various computational methods and techniques were presented and discussed, including: a generalised automated workflow for CFD validation and verification and development;
- GPU-based high-fidelity CFD using NekRS, which outperforms the CPU-based version and is used to generate data to improve coarser and faster running models;
- high-low fidelity thermal hydraulics coupling using the Functional Mockup Interface (FMI) standard to integrate AI-based reduced order models and Modelica-based system models with CFD.

Their application was discussed based on selected examples and should be further investigated to improve quality and performance and representativeness of engineering CFD applications.

The last two papers reported development, validation and application of novel 3D CFD tools. Both were built on top of the open-source platform OpenFOAM and aim at analysing safety aspects of Plate-type Fuel Reactor Core (CorTAF-PT) and steam generators (STAF).

2.3. Technical Session 2

2.3.1. Name of the session

TS-2 bubble dynamics

2.3.2. Session chairs

Emilio Baglietto (MIT), Igor Bolotnov (NCSU)

2.3.3. Summary of the session

The session was illustrated with several experiments which the CFD were trying to replicate with accuracy. The specific phenomena of bubble transport, bubble generation and pool scrubbing appear to be still a very challenging task and specific models and numerical apparatus are tied to CFDs to help them replicate the very specific phenomena related to bubbles. Nevertheless, the degree of accuracy self-imposed in this field appears to largely exceed the requirements for safety applications of CFD in conventional reactors.

2.4. Panel Session 1

2.4.1. Name of the session

PS-1 digital reactor project

2.4.2. Session chairs

Pierre Ruyer (EDF)

2.4.3. Summary of the session

The digital reactor project envisioned by EDF and presented by Chaï Koren is a next generation tool that allows coupling multi-physics and multi-scale (more specifically for thermal hydraulic tools). In the session, simulation software was discussed. The presentation was made of a French project aiming to be used both for engineering issues and for unit simulation for operators. Issues of interaction between modules and input or output are rather new. In this context, CFD plays a specific role as providing some data for realistic visualisation of underneath processes. The discussion that arose from the session was mainly focused on the qualification of the coupling and of surrogate models use, as well as the midterm perspectives concerning the evolution of such tools.

2.5. Technical Session 3

2.5.1. Name of the session

TS-3 aerosol and fission products transport

2.5.2. Session Chairs

Shuichiro Miwa (UT), Afaque Shams (KFUPM)

2.5.3. Summary of the session

The session consisted of four presentations. First, a talk was given on a CFD approach to simulate aerosol particle deposition for nuclear power plant safety and Fukushima Daiichi decommissioning applications. Some discussions followed about the meshing approach in

boundary layer, turbulence model selection, etc. The second presentation provided new information on computational modelling and validation of a modified MARPLE cascade impactor. Discussions focused on the sensitivity of particle shape in STAR-CCM+, mesh sensitivity in the impactor flow channels, etc. The third presentation was entitled "Experimental investigation of bubble hydrodynamics in the globule regime inside a shallow pool". Ongoing experimental work for CFD benchmarking was introduced in the presentation. The final presentation was on the simulation of noble metal particle growth and removal in the molten salt fast reactor. Two-phase flow consisting of helium gas bubbles in molten salt continuum was introduced and the CFD analysis results using existing interfacial drag models to predict void fraction and interfacial area concentration were reported.

2.6. Technical Session 4

2.6.1. Name of the session

TS-4 two-phase flow

2.6.2. Session chairs

Tomasz Kwiatkowski (NCNR), Ed Komen (NRG)

2.6.3. Summary of the session

2.6.4. Summary of the session

During this session, three oral presentations and two video presentations were made. The first presentation showed the Open FOAM hybrid model development and validation. Two contributions were made on the usage of CFD for design, for a heat pipe and a helical tube steam generator in a SMART reactor. A presentation focused on the pre-test analyses using the PANDA facility and the spargers, and finally one presentation combined the experimental and CFD work of heated liquid film in annular flow. In summary, it can be concluded that the field of two-phase flow is still very active, although the complexity of the phenomena in this field leads to a lower level of maturity with respect to single phase.

2.7. Technical Session 5

2.7.1. Name of the session

TS-5 numerical studies

2.7.2. Session chairs

Sofiane Benhamadouche (EDF), Matej Tekavcic (JSI)

2.7.3. Summary of the session

During this session, two presentations were made by KAERI using the CUPID code on which numerical investigations were tested for innovative small modular reactors. Additionally, a presentation on 2D turbulence model was given, focusing on the scaling uncertainty propagation and sensitivity analyses. There was also a presentation on preliminary CFD work on pebble beds that showed up to 100% error compared to correlations, which demonstrates that when applying new numerical methods to try to solve new phenomena related to new reactors, there is still a long way ahead, and further work is necessary.

2.8. Technical Session 6

2.8.1. Name of the session

TS-6 liquid metals

2.8.2. Session chairs

Vineet Kumar (ONL), Milorad Dzodzo (WEC)

2.8.3. Summary of the session

During this session, three presentations were made. The first one was entitled "Understanding the need for proper heat flux turbulent modelling for non-unity Prandtl number fluids."

Advances have been made in turbulence modelling of liquid metal flows, be it in challenging geometries such as wire-wrapped rod bundles applying Large Eddy Simulation (LES) under the presence of a blockage or in fundamental turbulent heat flux modelling for buoyancy-driven flow regimes. The turbulent heat flux modelling for low-Pr fluids is the culmination of more than two decades of work identifying the need to improve upon turbulent heat flux closures. This is done by moving away from simple Reynolds analogy-based gradient diffusion hypotheses to algebraic heat flux models (AHFM) which provide a good balance between numerical stability, computational runtime, and prediction accuracy. Models which can work well across flow regimes and are calibrated and validated for complex are currently needed, such as AFHM- SC, which is a proposed correlation.

The second presentation was entitled "Simulation of a partially blocked wire-wrapped fuel assembly using LES with wall functions". In this presentation, an LES simulation was used to simulate flow on a 61-pin wire-wrapped rod bundle under the presence of a blockage at the bundle periphery. Results were compared and agreed with PIV data. A pressure form loss coefficient due to the blockage was calculated.

The third presentation was entitled "Prediction of flow regime boundary and pressure drop for hexagonal wire-wrapped rod bundles using ANNs". This showed that, given the large experimental database available for wire-wrapped rod bundle geometry, especially PIV experimental data from the Texas A&M Thermal-Hydraulic Research Lab, an excellent code validation repository is available. While an excellent global pressure drop prediction was obtained using LES modelling with wall functions for sufficiently high Reynolds number in this highly complex geometry, more work is required to capture the asymmetrical flow distribution closer to the wrapped wire. Given the exhaustive number of model parameters required to predict the pressure drop across the wire-wrapped geometry, advances in surrogate modelling approaches such as artificial neural network (ANN) can be used to explore more accurate model formulations to estimate the transition-to-turbulence flow regime boundary and friction factor. Using the 5000+ rod bundle data points available with variation in number of rods, rod diameter, wire diameter, lattice pitch, etc., sufficient training and testing datasets are available to develop and test surrogate models. Excellent predictions were obtained, especially for friction factor for the ANN model when tested against both test data as well as limited blind data, in comparison to popular friction factor correlations.

2.9. Keynote Session 2

2.9.1. Name of the session

Towards multi-scale, multi-fidelity, multi-phase CFD of industrial benefit

2.9.2. Session chair

Martina Adorni (NEA)

2.9.3. Summary of the session

The session, presented by Ryan Tunstall, presented the latest advances and developments at Rolls Royce regarding a multi-scale, multi-fidelity, multi-phase CFD of industrial benefit. The main conclusion of the presentation is that robust, accurate and fast-running low TRL methods for component scale flow boiling are of potential benefit to industry, including multi-scale multi-fidelity multi-phase CFD, using surrogates to bridge scales and fidelities and collaborative validation over a range of scales and conditions. Additionally, natural circulation presents a further opportunity for benefits through improvements in thermal hydraulic analysis methods. Moreover, complementary experimental data are essential. Finally, an alignment and collaboration between industry and academia is a key to accelerated realisation of benefits with a focus on the phenomena and mechanisms above prototypicality.

2.10. Panel Session 2

2.10.1. Name of the session

Planning a computational fluid dynamics credibility assessment framework

2.10.2. Session chairs

Philippe Freydier (EDF)

2.10.3. Summary of the session

In this session, the regulatory body US NRC, represented by Joshua Kaizer and Noushin Amini, held an open discussion with the audience about the role of the regulator in this workshop. They directly tried to answer the question “Why are we here”? In that sense, the regulator was highlighting the fact that CFD applications are increasingly used among vendors and licensees, especially within advanced new reactors, but except for one specific application, there is a lack of general CFD guidance to assist NRC staff in their reviews of diverse CFD applications. There is a need to bridge industry guidance on verification, validation, and uncertainty quantification (VVUQ) of CFD to applications for nuclear reactor power. The regulator asked the audience for feedback, as, in their words, “There is a lot of best practices, but we want to write minimum standards”, which is a slightly different approach to VVUQ than what it is currently available. The feedback from the audience involved different proposals, from a CFD practitioner certification, on which part of the VVUQ is displaced to the person itself, saving time in the regulatory process, to the development of generic guidance, the same way it is done for dry cask applications. Nevertheless, the session finished inconclusively as the audience was divided on this concept; although the discussion was seen as necessary, more discussions are needed to reach a consensus.

2.11. Technical Session 7

2.11.1. Name of the session

Fuel fluid interactions

2.11.2. Session chairs

Pierre Ruyer (IRSN), Jan-Patrice Simoneau (EDF)

2.11.3. Summary of the session:

CFD grade experimental data were presented in two papers, with corresponding computational studies presented in both cases. Fine data about fluctuations were analysed and contributed to a better understanding of the process. The magnetic resonance velocimetry appears as a future technique and should therefore be considered. The third contribution showed CFD applications for improving the design of fuel and in-vessel equipment.

2.12. Technical Session 8

2.12.1. Name of the session

Verification and validation

2.12.2. Session chairs

Elia Merzari (PSU), Masaaki Tanaka (JAEA)

2.12.3. Summary of the session:

During this session, fundamental concepts of CFD that are applied daily were challenged and reassessed. For example, the Reynolds analogy used in RANS calculations was explicitly tested against challenging phenomena and conditions, and conclusions about the effects that it is provoking in CFD calculations showed how the buoyancy production term creates this model error. Additionally, a discussion on the different types of scaling of experimental facilities for SET, or IET, was presented, on which the benefits of combining H2TS and FSA scaling methods and CFD comparison of dimensionless numbers. The scaling analysis can support the choice of CFD domain, mesh size, and distribution. It can establish the needed time steps and support validation and CFD best practices. Also, it was shown how in some situations validated CFD models, based on the best practices, can support the scaling analysis and help to interpolate or extrapolate the distorted test results from the scaled facilities to the prototypical conditions. Finally, specific work on the NEA benchmark to evaluate CFD in branch line flows on which a novel experimental database of the temperature fluctuations inside the solid pipe wall of a dead leg flow was discussed.

2.13. Keynote Session 3

2.13.1. Name of the session

Experience in development, deployment and application of open-source CFD tools

2.13.2. Session chair

Emilio Baglietto (MIT)

2.13.3. Summary of the session

The successful adoption of computational fluid dynamics to consistently support safety-related applications will directly impact the timeline and success of advanced reactor deployment, as well as impact the operation and maintenance cost of the operating fleet. A fruitful discussion was held between the chair and the speakers (Chaï Koren and Dirk Lucas) on the open-source software verification requirements and quality assurance. This can be quite different for laboratory developed, open-source and commercial tools, and some challenges have been seen in training the regulators to move past the simple verification practices based on MMS towards a more advanced agile software development approach. There were further discussions on the topic of traceability. Safety-related application of CFD requires very consistent traceability of the process, which is greatly impacted by the software approach. For example, early use of CFD in support of safety-related applications came with an incredibly heavy documentation of how the mesh has been created and the solution had been performed, as it involved many user interactions. In this discussion, there was a consensus between the audience, chair and speakers that a lot of work must be carried out not only for the usage of CFD but also the usage of open-source CFD outside research centres. Related to the Panel Session 2, a strong effort in validation and verification guidelines would boost the usage of open-source codes, which almost invariantly was deemed as the next move of CFD practitioners. Finally, an important conclusion was reached among the participants that can be summarised in the air force saying "It's not the plane, it's the pilot". This expression encompasses the general feeling that it does not matter which code a CFD practitioner is using (commercial, open source, spectral methods, RANS, etc.), it is the skills and experience of the user that provide confidence in a CFD simulation, as any CFD properly used is suitable for most applications.

2.14. Technical Session 9

2.14.1. Name of the session

Verification and validation II

2.14.2. Session chairs

Ronald Lehnigk (HZDR), Ryan Tunstall (Rolls Royce)

2.14.3. Summary of the session

During this session, a presentation on the validation of multi-phase CFD frameworks for natural circulation was discussed for advanced reactors. It was stated that multi-phase CFD has only widely been applied to low void fraction flows in small geometry applications. At higher void fraction multiphase flows present in reactors, complex interactions occur that make their modelling challenging. The VOF method and a hybrid mixture-multiphase framework with large-scale interface capturing (MMP-LSI) methods are validated against experiments performed at the TOPFLOW and HUSTLE facilities. Further work is needed to develop models for these interactions to allow for their implementation in hybrid models. Other presentations focused on how to increase confidence in industry applications of CFD. New insights on how to use artificial intelligence for CFD validation purposes is also provided. Finally, the EDF in-house code software Saturne was assessed for unstable flow experiments with temperature fluctuation.

2.15. Technical Session 10

2.15.1. Name of the session

Severe accidents

2.15.2. Session Chairs

Kevin Fernández-Cosials (UPM/Texas A&M University), Marco Pellegrini (UT)

2.15.3. Summary of the session

Severe accidents are still an enormous source of uncertainties, both in the definition of initial and boundary conditions and in the development of the accident. CFD is not developed enough to tackle these with a sufficient degree of confidence as in other areas of nuclear safety. In this sense, the fields of application of CFD for severe accidents remain to be better justified and may be limited to complement the comprehensive analyses that can be done with established system codes (should the latter provide a reasonable result). Nevertheless, the work presented during the session fostered a good discussion.

3. Conclusion and recommendation

The technical session topics, as expected, were broad and varied, including such issues as advanced reactor modelling, flow mixing issues, boiling and condensation modelling, multiphase problems, liquid metals, severe accidents, verification and validation, and single and multiphase flow in reactor cores and sub-channels.

The discussions revealed enthusiasm about the use of CFD in the industry. However, a strong need for proper and easy-to-apply verification was identified and validation guidelines are required for this industry to move forward. The main problem is not that there are no verification and validation procedures, but rather the opposite: there are a lot of best practices which in most cases are hard and costly to develop, but the regulatory bodies need something simple and easy to implement as “minimum standards”.

As regards the use of open-source codes, there was a consensus among participants that this is the path forward. Open-source CFD codes provide flexibility, a large and engaged user community and economic benefits that commercial CFD codes lack. Nevertheless, it must be noted that most of the audience were developing careers in research centres or in academia, which could explain this unanimous agreement.

In relation to the necessity of the verification and validation tasks, a continuous effort is still required to look for new phenomena and experiments and develop specific benchmarks or studies to assess the capability of CFD codes to correctly address this specific matter.

Finally, it was also agreed that no matter which CFD a CFD practitioner is using (commercial, open source, spectral methods, RANS, etc.), the skills and experience of the user is what provides confidence in a CFD simulation, as any CFD properly used is suitable for many applications. As expressed in the saying “it’s not the plane, it’s the pilot”, it was agreed that CFD results should be independent of the code and driven by the methods and qualities of the users.

Appendix A: List of participants

First Name	Last Name	Affiliation
Martina	Adorni	NEA
Imran	Afgan	Khalifa University
Noushin	Amini	US NRC
Ojasvin	Arora	Texas A&M University
Vittorio	Badalassi	Oak Ridge National Laboratory
Steven	Begnaud	Texas A&M University
Steve	Bajorek	US NRC
Sofiane	Benhamadouche	EDF (Electricité de France)
Igor	Bolotnov	North Carolina State University
Octabio	Bovati	Texas A&M University
Christopher	Boyd	US NRC
Lane	Carasik	Virginia Commonwealth University
Yun Je	Cho	Korea Atomic Energy Research Institute
Michael	Conner	Westinghouse Electric Company
Kevin	Deiter	Becker Technologies
Seong Ju	Do	Korea Atomic Energy Research Institute
Kristine	Donatello	Texas A&M University
Milorad	Dzodzo	Westinghouse Electric Company
Kevin	Fernández-Cosials	Texas A&M University/ Universidad Politécnica de Madrid
Carlo	Fiorina	Texas A&M University
Edo	Frederix	NRG
Philippe	Freydier	EDF (Electricité de France)
Nabil	Ghendour	Paul Scherrer Institute
Yassin	Hassan	Texas A&M University
Joseph	Hegarty	Rolls-Royce
Phil	Hilton	Rolls-Royce
Thomas	Höhne	HZDR – Helmholtz-Zentrum Dresden-Rossendorf
Haifu	Huang	French Alternative Energies and Atomic Energy Commission
Anna	Iskhakova	North Carolina State University
Prashant	Jain	Oak Ridge National Laboratory
Kristine	John	University of Rostock
Joshua	Kaizer	US NRC

First Name	Last Name	Affiliation
Stephan	Kelm	FZJ (Forschungszentrum Jülich)
Doh Hyeon	Kim	Korea Advanced Institute of Science and Technology)
Hansol	Kim	Texas A&M University
Ed	Komen	NRG
Chai	Koren	EDF (Electricité de France)
Vineet	Kumar	Oak Ridge National Laboratory
Tomasz	Kwiatkowski	National Center for Nuclear Research, Poland
Kwun Ting	Lau	City University of Hong Kong
Ronald	Lehnigk	HZDR – Helmholtz-Zentrum Dresden-Rossendorf
Xitong	Liu	Korea Atomic Energy Research Institute
Dirk	Lucas	HZDR – Helmholtz-Zentrum Dresden-Rossendorf
Muhammad Sohaib	Malik	University of Illinois
Laurie	Mcarthur	Texas A&M University
Zhongkai	Mei	Karlsruhe Institute of Technology
Elia	Merzari	Pennsylvania State University
Shuichiro	Miwa	University of Tokyo
Yuria	Okagaki	Japan Atomic Energy Agency
Daniel	Orea	Texas A&M University
Erdal	Ozdemir	University of Tokyo
Marco	Pellegrini	University of Tokyo
Victor	Petrov	ETH Zurich
Markus	Rehm	Framatome
Yago	Rivera	Universitat Politècnica de València
Pierre	Ruyer	Institut de Radioprotection et de Sûreté Nucléaire
Marcos	De Sena	Texas A&M University
Joseph	Seo	Texas A&M University
Afaque	Shams	King Fahd University of Petroleum and Minerals
Avadhesh Kumar	Sharma	NRG
Jan-patrice	Simoneau	EDF (Electricité de France)
Noah	Sutton	Texas A&M University
Masaaki	Tanaka	Japan Atomic Energy Agency
Emre	Tatli	Westinghouse Electric Company
Matej	Tekavčič	Jozef Stefan Institute
Ryan	Tunstall	Rolls Royce
Guilherme	Vilela	Texas A&M University
Haixia	Wang	Institute of Nuclear Energy Safety Technology, China

First Name	Last Name	Affiliation
Xicheng	Wang	KTH Royal Institute of Technology
Kara	Wilke	Texas A&M University
Ralph	Wiser	Massachusetts Institute of Technology
Weiyi	Yao	University of Tokyo
Dali	Yu	Institute of Nuclear Energy Safety Technology, China
Boštjan	Zajec	Jozef Stefan Institute
Chunjie	Zeng	Xi'an Jiaotong University

Figure 0.1. Group photo of the CFD4NRS-9 participants

Appendix B: Technical Sessions Detailed Schedule

Technical Session 1 – Computational Methods. Feb 20, 10:30-12:00, Hagler Room.

Chair(s)

Stephan Kelm (IEK)

Chai Koren (EDF)

Presentations

1. **Creating reproducible, scalable, portable and adaptable CFD validation workflows with snakemake.**

   R. Lehnigk, D. Lucas, M. Rehm, F. Schlegel

   HZDR – Helmholtz-Zentrum Dresden-Rossendorf

2. **From supercomputing simulations to engineering approaches: building a multiscale framework.**

   Elia Merzari

   Pennsylvania State University

3. **High–low fidelity thermal hydraulic coupling using ai/machine learning algorithms.**

   Wesley Williams, Vineet Kumar, Elvis Dominguez-Ontiveros

   Oak Ridge National Laboratory

4. **Development & validation of CORTAF-pt: a 3d thermal-hydraulic characteristic analysis code for plate-type fuel reactor core.**

   Xitong Liu, Kai Liu, Mingjun Wang, Wenxi Tian, Suizheng Qiu, G. H. Su

   Korea Atomic Energy Research Institute

5. **Three-dimensional nuclear steam generator thermal-hydraulics analysis code staff—development and application.**

   Zeng Chunjie, Wang Mingjun, Tian Wenxi, Qiu Suizheng, Su Guanghui

   Xi'an Jiaotong University

Technical Session 2 – Bubble Dynamics. Feb 20, 10:30-12:00, Room 1011B.

Chair(s)

Emilio Baglietto (MIT)

Igor Bolotnov (NCSU)

Presentations

1. **CFD investigation on single bubble rising hydrodynamics and wall effect during pool scrubbing.**

   Weiyi Yao, Marco Pellegrini, Ozdemir Erdal, Koji Okamoto.

   University of Tokyo

2. **Simulation of single ellipsoidal bubble dynamics for pool scrubbing.**

   Yuria Okagaki, Kosuke Motegi, Satoshi Abe

   Japan Atomic Energy Agency

3. **Experimental data on bubble size distributions in horizontal annulus.**

   Boštjan Zajec, Leon Cizelj, Boštjan Končar

   Jozef Stefan Institute

4. **Characterisation of steam chugging by experimental and computational analyses.**

   Marco Pellegrini, Nejdet Erkan, Shuichiro Miwa, Koji Okamoto

   University of Tokyo

5. **Interface-capturing flow boiling simulation with phasta: Progress, challenges, and path forward.**

   Anna Iskhakova, Nam T. Dinh, Igor A. Bolotnov

   North Carolina State University

6. **Experimental study on bubble dynamics for wall boiling model through high-speed infrared thermometry.**

   Song Ni, Kwun Ting Lau, Jiyun Zhao

   City University of Hong Kong

Technical Session 3 – Aerosol and Fission Products Transport. Feb 20, 14:00-15:30, Hagler Room.

Chair(s)

Shuichiro Miwa (UT)

Afaque Shams (KFUPM)

Presentations

1. **A CFD approach to simulation of particle deposition for nuclear power plant safety.**

   Erdal Ozdemir, Marco Pellegrini, Avadhesh Kumar Sharma, Shuichiro Miwa, Shunichi Suzuki, Koji Okamoto.

   University of Tokio

2. **Computational modelling and validation of a modified MARPLE cascade impactor.**

   Vineet Kumar, Sasikumar Yadukrishnan, Rose Montgomery

   Oak Ridge National Lab

3. **Experimental investigation of bubble hydrodynamics in the globule regime inside a shallow pool.**

   Nabil Ghendour, Detlef Suckow, Abdelouahab Dehbi, Michael Klauck

   Paul Scherrer Institute

4. **Simulation of noble metal particle growth and removal in the molten salt fast reactor.**

   E.M.A. Frederix and E.M.J. Komen

   Nuclear Research and Consultancy Group

Technical Session 4 – Two-phase Flow. Feb 20, 14:00-15:30, Room 1011B.

Chair(s)

Tomasz Kwiatkowski (NCNR)

Ed Komen (NRG)

Presentations

1. **The morphology adaptive multifield solver openFOAM-hybrid and its application to multiphase flow problems in nuclear safety.**

   Benjamin Krull, Dirk Lucas, Richard Meller, Fabian Schlegel, Matej Tekavčič

   HZDR – Helmholtz-Zentrum Dresden-Rossendorf

2. **Heated liquid film in vertical free fall air-water annular flow.**

   Y. Rivera, c. Berna, y. Córdova, J.L. muñoz-cobo, A. Escrivá

   Universitat Politècnica de València

3. **Pre-test design of panda experiments with steam injection through a sparger pipe by effective heat and momentum models.**

   Xicheng Wang, Dmitry Grishchenko, Pavel Kudinov

   KTH Royal Institute of Technology

4. **CFD investigation of two-phase flow pressure drop in helical tube steam generator for lwr based SMR application.**

   Doh Hyeon Kim, Seunghwan Oh, Jeong Ik Lee

   KAIST (Korea Advanced Institute of Science and Technology)

5. **CFD simulation on the transient heat and mass transfer performance of a water-copper wicked heat pipe.**

   Dali Yu,, Jian Liu,B, Chongju Hu

   Institute of Nuclear Energy Safety Technology, China

Technical Session 5 – Numerical Studies. Feb 20, 15:45-17:15, Hagler Room.

Chair(s)

Sofiane Benhamadouche (EDF)

Matej Tekavcic (JSI)

Presentations

1. **CFD for natural circulation flows: numerical investigations with trioCFD for a pitchfork bifurcation in the framework of system scaling uncertainty quantification.**

   Haifu Huang, Jorge Perez, Nicolas Alpy, Marc Medale

   French Alternative Energies and Atomic Energy Commission

2. **Highly scalable meshless multi grid solver for simulation of 3d reactor vessel analysis.**

   Seong Ju Do, Han Young Yoon

   Korea Atomic Energy Research Institute

3. **Assessment of the cupid code for multi-dimensional analysis of innovative small modular reactor.**

   Yun-je Cho, Ji-Hyun Sohn, Seong-Jun Lee, Han-Young Yoon

   Korea Atomic Energy Research Institute

4. **Multiple flow regime CFD simulating generic pool boiling.**

   T. Höhne, D. Lucas

   HZDR – Helmholtz-Zentrum Dresden-Rossendorf

5. **CFD simulation for evaluating pressure drop and heat transfer correlations for pebble bed reactor.**

   Muhammad Sohaib Malik, Jiaqi Chen and C.S. Brooks

   University of Illinois

6. **Numerical simulation of tritium behaviour in tritium confinement system for China fusion engineering test reactor.**

   Haixia Wang, Xuewei Fu, Jincheng Han, Wenhao Wu, Taosheng Li, Jie Yu

   Institute of Nuclear Energy Safety Technology, China

Technical Session 6 – Liquid Metals. Feb 20, 15:45-17:15, Room 1011B.

Chair(s)

Vineet Kumar (ONL)

Milroad Dzodzo (WEC)

Presentations

1. **Understanding the need for proper turbulent heat flux modelling for non-unity Prandtl number fluids**

   Afaque Shams

   King Fahd University of Petroleum and Minerals

2. **Simulation of a partially blocked wire-wrapped fuel assembly using les with wall functions.**

   Octavio Bovati and Yassin Hassan

   Texas A&M University

3. **Prediction of turbulent heat transfer in buoyancy-affected flow regime.**

   Andrea Pucciarelli, Afaque Shams and Nicolad Forgione

   King Fahd University of Petroleum and Minerals

4. **Prediction of flow regime boundary and pressure drop for hexagonal wire-wrapped rod bundles using artificial neural networks.**

   Hansol Kim and Yassin A. Hassan

   Texas A&M University

Technical Session 7 – Fuel Fluid Interactions. Feb 21, 10:30-12:00, Hagler Room.

Chair(s)

Jan-patrice SIMONEAU (EDF)

Pierre Ruyer (IRSN)

Presentations

1. **Validation of fuel assembly CFD models using magnetic resonance velocimetry and turbulence measurements for 5x5 swirl type mixing vane configuration.**

   Martin Bruschewski, Kristine John, Sven Grundmann, Markus Rehm, Hidajet Hadžić, Peter Pohl

   University of Rostock

2. **Effect of baffle jetting on the heat transfer and fluid flow within rod assembly.**

   Mohamed Ali, Ahmed Alkaabi, Yacine Addad, Imran Afgan

   Khalifa University

3. **Use of computational fluid dynamics in Westinghouse innovation projects.**

   Michael E. Conner, Milorad Dzodzo, Emre Tatli, Yiban Xu, Paolo Ferroni, Jorge V. Carvajal

   Westinghouse Electric Company

4. **Perspectives on the use of wall-resolved large eddy simulation for flow induced vibrations.**

   Sofiane Benhamadouche and Thomas Norddine

   EDF (Electricité de France)

5. **Utilisation of 3d boron asymmetry information in nuclear reactor generated from CFD for 1d safety analysis.**

   Seunghwan Oh, Doh Hyeon Kim, Jeong Ik Lee

   KAIST (Korea Advanced Institute of Science and Technology)

Technical Session 8 – Verification and Validation I. Feb 21, 10:30-12:00, Room 1011B.

Chair(s)

Elia Merzari (PSU)

Masaaki Tanaka (JAEA)

Presentations

1. **Scaling analysis as a support of CFD best practices.**

   Milorad B. Dzodzo

   Westinghouse Electric Company

2. **Novel measurements of fluctuating temperature in the solid pipe wall for validation of CFD of stratification and thermal fatigue in closed branch line flows.**

   Howard Richard, Angele Kristian, Veber Pascal, Edh Nicolas, Olivier Braillard, Victor Petrov, Annalisa Maneira

   Paul Scherrer Institute

3. **A NEA/OECD benchmark experiment to evaluate CFD in branch line flows.**

   Angele Kristian, Howard Richard, Veber Pascal, Edh Nicolas, Olivier Braillard, Victor Petrov, Annalisa Maneira

   Paul Scherrer Institute

4. **Wrong but not guilty: the Reynolds analogy and model error in CFD.**

   Ralph Wiser, Emilio Baglietto

   Massachusetts Institute of Technology