# Accelerating international cooperation on SMR safety research

***The OECD Nuclear Energy Agency (NEA) Working Group on the Analysis and Management of Accidents (WGAMA)***

H. NAKAMURA

Japan Atomic Energy Agency (JAEA)

Tokai, Japan

A. BENTAIB

Institut de Radioprotection et de Sûreté Nucléaire (IRSN), PSN-RES/SAM, F-92260

Fontenay-aux-Roses, France.

P. RUYER

Institut de Radioprotection et de Sûreté Nucléaire (IRSN), PSN-RES/SEMIA, F-13115

Saint-Paul-lez-Durance, France.

F. MASCARI

Agenzia Nazionale per le Nuove Tecnologie, l'Energia e lo Sviluppo Economico Sostenibile (ENEA), Bologna, Italy

M. ADORNI

OECD Nuclear Energy Agency (NEA)

Paris, France

Email: martina.adorni@oecd-nea.org

**Abstract**

The Working Group on the Analysis and Management of Accidents (WGAMA) addresses OECD Nuclear Energy Agency (NEA) activities related to potential design-basis accident (DBA) and beyond design-basis accident (BDBA) in nuclear reactors and related technologies [1]. The group addresses safety issues of existing nuclear reactors and related technologies as well as emerging challenges on evolutionary and innovative reactor designs and nuclear technologies, including Small Modular Reactors (SMRs) [1]. For these purposes, the WGAMA has coordinated workshops, technical publications and research activities in the fields of thermal-hydraulics (T/H), computational fluid dynamics (CFD) and severe accidents (SAs) to improve knowledge of accidents and of the confidence of the scientific calculation tools used in safety studies, namely safety analysis codes or tools.

The WGAMA works on the review of its past activities in the fields of thermal-hydraulics (T/H), computational fluid dynamics (CFD) and severe accidents (SAs) to assess the applicability of their outcomes to safety assessment of the innovative reactor designs, and defines what extra work will be needed. Subjects of high priority were identified and discussed in [9].

Regarding the verification and validation (V&V) of safety analysis codes, the NEA has developed CSNI Code Validation Matrix (CCVM) since 1993. The CCVM gathers the largest set of up-to-date test data for various technologies and reactor designs including relevant phenomena that dominate different types of accidents and transients; phenomena occurrence vs experimental facilities; and suitability of the experimental facilities, thus databases, necessary for the code assessment. This internationally agreed CCVM is the great achievement to systematically perform code validation, assessment, and improvement, including quantitative assessment of uncertainties in the modelling of individual phenomena based on the best sets of openly available test data. To support the V&V of safety assessment codes for SMRs, however, significant efforts will be needed via updating the current CCVM, extending it to cover experiments thus test facilities that properly represent or simulate normal and accident phenomena unique to SMR designs with new yet advanced technologies.

The transfer of knowledge gained from key NEA/CSNI activities is one of the most important topics, not only for newcomers to the field, but also for all WGAMA members. The THICKET seminars, which aim to disseminate the knowledge, skills and experience in nuclear safety acquired in the course of activities over the last few decades, are also discussed.

This paper aims at summarizing the recent achievements of the WGAMA.

## INTRODUCTION

According to it's mandate, the WGAMA assesses and, where necessary, strengthens the technical basis needed for the prevention, mitigation and management of potential accidents in nuclear reactors and related technologies, and to facilitate international convergence on safety issues, safety assessments and accident management (AM) measures and strategies [1]. Priority setting is based on established criteria of the Committee on the Safety of Nuclear Installations (CSNI) [2], in particular on safety significance and risk and uncertainty considerations [3]. In order to fulfil these objectives, the WGAMA:

* Exchanges technical experience and information relevant for resolving current or emerging safety issues;
* Promotes the development of phenomena-based models and codes used for the safety analysis, including the performance of benchmarking exercises;
* Assesses the state of knowledge in areas relevant for the accident analysis;
* Where needed, promotes research activities aimed to improve such understanding, while supporting the maintenance of expertise and infrastructure in nuclear safety research.

The WGAMA reports its activities to the CSNI and assists the Committee with its work. The WGAMA provides answers to questions from the CSNI and the Committee on Nuclear Regulatory Activities (CNRA) [4]. The WGAMA engages with other international bodies specialised in similar sets of activities to ensure complementarity and increase synergy, notably the International Atomic Energy Agency (IAEA).

The WGAMA promotes workshops (WSs) and conferences with summary reports and proceedings, as well as joint research proposals. The WGAMA produces state-of-the-art report (SOAR), technical opinion paper (TOP) and other technical reports, including phenomena identification ranking table (PIRT), CSNI Code Validation Matrix (CCVM)), and international standard problem (ISP) and benchmark exercises. The activity results of tentative and long-term task groups (TGs) are mostly published as technical reports too. Final reports are issued as CSNI reports [1, 5], all of which provide achievement status and recommendations [6]. To indicate the WGAMA activity in a summarized form, papers to international conference and Journals are also prepared, such as [7, 8]. The information below in this section is summarized mainly from [9].

## OVERVIEW OF WGAMA ACTIVITY

As mentioned above, the WGAMA activities are organized in around three fields: T/H, CFD and SAs. The following sections provide an overview of the recent achievements for each field.

### Thermal-hydraulics (T/H)

#### Reliability assessment of passive system

The WGAMA prepared the "Status report on thermal-hydraulic passive systems design and safety assessment" [10] from an activity coordinated by the University of Pisa (UNIPI).

Key conclusion from the status report activity was as follows [10]: “Suitable analyses and specific demonstrations of the adequacy of the design and operation of thermal-hydraulic passive systems, namely those based on natural circulation, are required to demonstrate the safety of nuclear reactors relying on such systems. In other words, passive systems may contribute to improving the safety of nuclear power plants, provided related safety targets are demonstrated with the methods, approaches and data (e.g. experimental database) available to industry and regulators.”

#### Modelling robustness of safety analysis codes

Reference [9] explains important progress in the WGAMA activities related to the modelling robustness of safety analysis codes which is a central important subject for the nuclear safety design assurance through reactor safety assessment. The WGAMA has therefore historically contributed to the code validation effort by the international standard problem (ISP) as a kind of benchmark study [11], including uncertainty quantification activities such as ATRIUM [12], SAPIUM [13], PREMIUM [14] and BEMUSE [15] related to PWR DBA safety assessment. Regarding the severe accident, Fukushima-Daiichi (1F) accident BSAF [16] is one of the important examples. T-junction [17] and GEMIX [18] are examples for CFD code improvements. These efforts related to safety evaluation of the operating reactors should form a basis of the safety evaluation techniques for emerging reactor designs including SMRs.

the Nuclear and Industrial Engineering (NINE) together with the organised a conference on BEPU-2024 to discuss Best Estimate Plus Uncertainty methods [1] with the objective to summarize the current status of the development and use of BEPU methods as well as challenges in applying these methods to multi-discipline (including multi-physics) modelling and simulation methods.

### Computational fluid dynamics (CFD)

#### Modelling innovation in CFD

Reference [9] contains important progress in the WGAMA activities related to the modelling innovation in CFD. The WGAMA CFD task group (TG) recently finalized a report on uncertainty quantification (UQ) when CFD is applied to the nuclear safety assessment. Despite CFD solves the most basic fluid dynamics equations, identification of uncertain parameters of a given problem, so-called "input uncertainties", is not straightforward. Recommendations have been formulated to reduce errors based on numeric sources, as well as computational cost, which are necessary when the safety assessment of innovative nuclear technologies is concerned.

Furthermore, reducing uncertainty for CFD depends mainly on the quality of the experimental data used in the validation process. The CFD-TG is also discussing data preservation, large volumes of data are needed for the safe operation of nuclear installations. The application of CFD needs new and more stringent requirements concerning experimental data [22]. Thus, databases needed for the verification and validation (V&V) of CFD codes should be identified and verified to duly confirm their applicability for the specific purpose of nuclear safety.

As noted in [9]: “CFD is a numerical method of large interest for nuclear safety study-related applications with already a high maturity level for single-phase flows. It should be increasingly part of the safety demonstration in the coming period, as a more suitable analysis tool for emerging innovative reactor designs”. The WGAMA keeps updating and sharing the CFD capability through the CFD-TG activities.

### Severe accident (SA)

#### Severe accident management (SAM) countermeasures

Recent WGAMA activities and achievements in the area of SA with relevance to SAM countermeasures include the 2018 International Severe Accident Management Conference (ISAMC-2018) [23], the recently published report on Long-Term Management and Actions for a Severe Accident in a Nuclear Power Plant [24], and the summary of the specialist WS "Reactor core and containment cooling systems, long-term management and reliability (RCCS-2021)" held in 2021 [25].

#### Advanced measurement methods and instrumentation

In 2020, under COVID crisis, a specialist WS SAMMI-2020 was held on-line on Advanced Measurement Method and Instrumentation for enhancing SAM in a NPP, addressing Emergency, Stabilisation and Long-term Recovery Phases [26]. As an updated specialist workshop that also deals with measurement methods for safety research experiments for both T/H and SA, WGAMA organized the SWINTH-2024 workshop to discuss advanced instrumentation and measurement techniques for nuclear reactor thermal hydraulics and severe accidents [1].

#### State-of-Art-Report (SOAR) on hydrogen and carbon monoxide risk in late phases of SA

The SOAR provides an overview of the main results obtained in managing the risks associated with hydrogen (H2) and carbon monoxide (CO) in nuclear power plants. To this end, it examines the behaviour of these combustible gases, starting with their production, distribution in the containment atmosphere, taking into account the effect of safety systems such as water sprays and recombiners, and ending with an assessment of their combustion regimes. Each stage is closely linked, enabling risk mitigation measures and the management of serious accidents to be continuously refined. The compilation of this report is not only essential for comprehensive containment analyses, but also extends its applicability to safety and maintenance considerations, ensuring a holistic approach to the mitigation and management of combustible gas risks under SA conditions.

## PLANNED FUTURE ACTIVITIES

### Update and extension of CCVM (CSNI Code Validation Matrix)

The WGAMA has made a significant effort to contribute and even promote reliable reactor safety assessment by providing code validation methods (e.g., CCVMs) and experimental data for the validation, and by enhancing the understanding of various kinds of T/H phenomena that may appear during reactor accidents. The CCVM was initially formulated for the preparation and utilisation of well-validated T/H codes by summarising the knowledge in a form of PIRT on the characteristics (and availability) of experimental facilities in terms of accident phenomena, which thus required code capabilities, with priority.

The WGAMA has developed many CCVMs since 1987, from the era of PWG-2 [see 8], not only for the accident phenomena that may appear in a reactor system [27-31], but also for the in-vessel core degradation [32, 33], and for the accident phenomena in a containment vessel [34]. Related experimental data are given through the NEA Data Bank for the SETs [35] and IETs [36], respectively.

The review and update of the past established CCVMs is under planning in response to the recent updating of models and correlations employed in the computer codes for safety analyses, by taking into account the safety assessment of advanced reactors that requires precise representation of all new features in the accident phenomena in response to the new designs. The CCVMs may need further harmonization and updating in accordance to such requirements to firmly confirm the applicability of the computer codes to the safety assessment of the advanced reactor design of interest.

Now, we have the T/H codes for the reactor safety assessment, as accumulated/tested essence of historical code development and validation efforts for the operating NPPs. They would be applicable for the advanced reactor designs including SMRs too. However, the PIRT and thus CCVM on the accident sequence and phenomena should be unique, and validity confirmation is necessary for each of new reactor designs. Strongly suggested here is to establish a CCVM specific to the reactor design of concern to avoid any lacking in the safety analysis subjects, based on the reactor prototype condition tests and/or the properly-scaled simulation experiments. Establishment of own computer code made from a combination of prediction models and correlations that fully cover expected accident conditions specific to the rector design should be the first yet necessary step to successfully achieve required safety assessments.

Connected to this topic, the task group (TG) “Harmonisation of Methodologies for System Thermal-Hydraulics Experimental Meta-Data Preservation, Collection and Qualification” (THEMPo) is under progress, aiming to develop, improve and then harmonize existing methodologies for collection, preservation, qualification, organization and then use of an exhaustive set of experimental information (SEI). The TG will provide the guide for the creation of a relational database of the experimental meta data.

### Knowledge transfer: THICKET

The WGAMA has organized the THICKET Seminar for the Transfer of Competence, Knowledge and Experience Gained through CSNI Activities in T/H Field. The seminar aims to disseminate the T/H knowledge, competence, and experience acquired through CSNI activities during the last three decades to newcomers in the nuclear sector. A series of seminars has been done, by the WGAMA senior experts who have contributed substantially to the current CSNI activities, at Saclay (2004, France), Pisa (2008, Italy), Paris (2012, France), and Budapest (2016, Hungary), each with over 30 participants. The next 5th seminar will be organized with new subjects based on recent CSNI activities, in such safety-relevant fields as T/H, CFD, SA, fuel safety, Probabilistic Safety Assessment (PSA) and WGAMA-relevant NEA JPs including 1F-related JPs.

The format of the seminar will basically follow the lecture method of the past seminars, but with emphasis on key nuclear safety-relevant activities such as ISPs, CCVMs, SOARs, SEG reports, TOPs, code V&V, user effect, scaling, uncertainties, source term, fuel degradation, melt behaviours including MCCI and FCI, and LTM. The emphasis will be given to recent and priority activities. Collaborative effort with CSNI WGFS and WGRISK is foreseen to deepen understanding on fuel behaviour under reactor accidents and risk perspectives on the reactor accident consideration and decision making. Application of safety-relevant findings to the design of non-water-cooled reactors will also be addressed. The lecture contents are, as such, utterly revised from the previous THICKET, to duly transfer the fundamental yet precisely updated knowledge through the CSNI activities to form a firm basis for each participant to confront any safety-relevant subjects for operating and emerging reactor designs including water-cooled SMRs. The seminar is planned at Lucca, Italy in 2025.

## Conclusive Remarks

This paper briefly summarizes most recent achievements and current status of the NEA/CSNI WGAMA activities, with the scope of several future challenges to properly respond for imminent safety assessment needs against recent reactor development including some advanced reactor designs including SMRs.

The WGAMA major outcomes were reviewed to draw technically meaningful achievements applicable for the advanced reactor designs, as discussed in [9]. Updating of the CCVMs with substantial extension to firmly conduct necessary V&V of safety assessment codes was identified as a key to realize the advanced reactor designs including SMRs steadily yet swiftly as much as possible. Along with such technical efforts, the knowledge transfer seminar, THICKET, will be done further to foster the building of knowledge base essential for the future experts who will pursue the safety of emerging nuclear reactors including SMRs.

In summary, as discussed in [9], the WGAMA achievements especially in the safety assessment of operating NPPs in the three fields of activities for T/H, CFD and SA, based on the productive efforts and profound experiences, will be of great help for the continuous safety improvements required for the advanced reactor designs including SMRs.

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