ONGOING ACTIVITIES OF THE WORKING GROUP ON ACCIDENT MANAGEMENT AND ANALYSIS (CSNI/WGAMA)

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Abstract

The CSNI Working Group on the Analysis and Management of Accidents (WGAMA) is committed to advancing the understanding of the physico-chemical processes of accident phenomenology in current and advanced reactors. As a result, it addresses a broad spectrum of safety issues related to the reactor coolant system and the containment including safety and auxiliary systems for management of design-basis and severe accidents. The present paper succinctly reviews the ongoing diverse activities in the fields of thermal-hydraulics, Computational Fluid Dynamics (CFDs) applied to nuclear reactor safety and severe accidents. Descriptions and overviews of the THICKET-4 seminar, the CFD4NRS-6 workshop, the GEMIX benchmark, the status report on long term management of severe accidents, the technical opinion paper on fuel-coolant interactions and the insights gained concerning the analytical support of Severe Accident Management Guidelines (SAMGs), will be provided. Finally, potential forthcoming activities will be mentioned.

Keywords: Accident analysis, management of accidents.

1. INTRODUCTION

The Working Group on Analysis and Management of Accidents (WGAMA) is one of the nine working groups in the frame of the Committee on the Safety of Nuclear Installations (CSNI) of the OECD/NEA (Nuclear Energy Agency). Fig. 1 shows the link of the WGAMA in the CSNI framework. The overall WGAMA objectives are: to assess and strengthen the technical basis needed for the prevention, mitigation and management of potential accidents in nuclear power plants; and to facilitate international convergence on safety issues and accident management analyses and strategies. To fulfil this objective, the Working Group 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, assesses the state of knowledge in areas relevant for the accident analysis and, where needed, promotes research activities aimed to improve such understanding, while supporting the maintenance of expertise and infrastructure in nuclear safety research. Regardless the activity, the intention is always to make significant contributions to the regulatory decision-making concerning prevention and management of accidents, understanding of specific events and identification of possible preventive measures, and to the state of knowledge and knowhow.

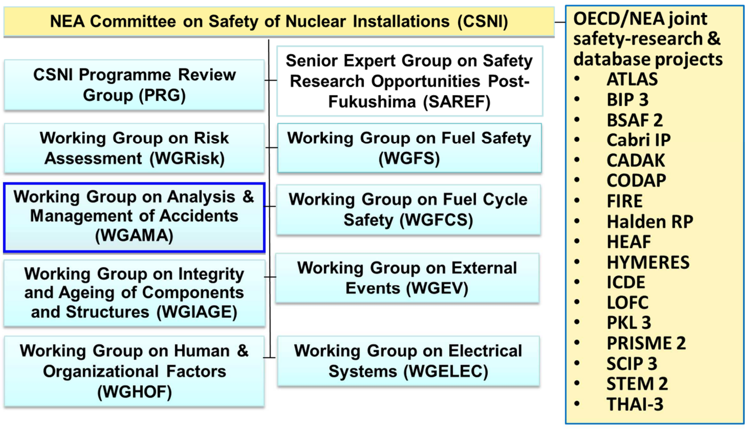

Fig.1. Working Groups and Project under the NEA/CSNI framework

Through its activities the Working Group provides answers to CSNI on posed questions and/or challenges on existing reactors, as requested, in the form of state-of-the-art and other types of technical reports, workshops and related proceedings, benchmarking exercises and joint research proposals. Each specific activity is usually undertaken by what is called a task group, which usually consists of a small number of national experts on the task to be addressed. Priorities are given based on criteria of safety significance and risk and uncertainty considerations.

Given the above objective, there are a number of technical areas that are within the scope of WGAMA. Just to give a few examples: reactor coolant system thermal-hydraulics; scaling of thermal hydraulics systems; best estimate and uncertainty analysis methods, design-basis accident including ECCS (Emergency Core Cooling System) strainer clogging; pre-core melt conditions and progression of accident and in-vessel phenomena; coolability of over-heated cores; ex-vessel corium interaction with concrete and coolant; in-containment combustible gas control; physical-chemical behavior of radioactive species in damaged plants; combustion phenomena; spent fuel pool accidents; informing severe accident management actions through analysis.

WGAMA has about 100 national delegates ensuring the efficient implementation of its broad work programme. The group has a Chair, a Vice-Chair, a Secretary, a Bureau and Task Leaders. The Bureau members play a key role providing technical and strategic advice to the Chair and Vice-Chair while the NEA Secretariat (through NEA's Nuclear Safety Technology and Regulation Division) provides support on organizational, logistic and, sometimes, strategic matters with respect to all WGAMA activities. The Chair and Vice-Chair take over the chairing of WGAMA meetings and monitor the progress of the activities, which they report on annually to CSNI. Specialists other than the WGAMA delegates can work on WGAMA activities; in recent years, more than 250 specialists have been actively contributing to WGAMA's work.

The present paper outlines the activities within the WGAMA. An overview is provided so that this article becomes a sort of directory of current WGAMA activities, including brief introductions and current status of the on-going activities.

2. BRIEF OVERVIEW of RECENTLY FINISHED ACTIVITIES

More than a decade ago, WGAMA decided to foster the use of CFD (Computer Fluid Dynamics) for nuclear safety. Since then three major achievements have been accomplished: best practice guidelines for the application of CFD on single phase issues of relevance in Nuclear Reactor Safety, (NRS) in which the basis for a sound validation is established along with advice for selection of physical models, nodalization schemes and numerical options [1]; an assessment of CFD codes for NRS, in which a compendium of current application areas and a catalogue of experimental validation data relevant to these applications are given together with gaps and recommendations to fill them up [2]; and, of utmost relevance, an attempt to extend CFD codes to 2-phase flow safety problems in more than 25 NRS problems where two-phase CFD may bring real benefit, in which attention has been focused on filtering of equations; dispersed flows and free surface flows. In the frame of these activities international benchmarks have been organized to test CFD capabilities to address reactor issues [3]. The last benchmark will be the first Uncertainty Quantification exercise on a rather simple mixing problem in presence of buoyancy effects. This benchmark has been preceded by a review of uncertainty methods (propagation of input parameters uncertainties vs. extrapolation of accuracy) for their application to CFD calculations when addressing thermal-hydraulic NRS issues [4].

The outstanding relevance of scaling in NRS and, particularly, in system thermal-hydraulics has drawn WGAMA's attention and a Status Of the Art Report (SOAR) has been recently approved by CSNI [5]. Given the high complexity of a nuclear power plant (NPP), models development and validation have been based on scaled-down mock-ups and conditions as close as possible to what is foreseen under postulated scenarios. After discussing the key areas and approaches for scaling, the SOAR collects evidences that point out that accuracy of thermal-hydraulic codes predictions may not depend on the scale of experiments, so that they might become a useful tool for addressing the scaling issue.

An international Iodine workshop was organized in March 2015 in Marseille jointly by OECD/NEA, the NUGENIA association, the European Commission and IRSN. Generally speaking the workshop intended to assess the recent progress made on Source Term research and its application in accident management. The essence of the conclusions and recommendations of the workshop regarding source term research and its implementation in tools supporting accident analysis and management including emergency response are detailed in a separate specific paper [6]. They mostly concern the necessity (1) to perform additional research focused on reactor applications to progress in the assessment of the potential effects of "delayed" FP re-emission in SA from deposits on RCS (Reactor Coolant System), containment and solid filters surfaces and from pools (sumps, suppression pools, liquid pools in filters) on source term evaluations (2) to deepen the assessment of the validity of source term related models implemented in SA system codes and of methods for source term evaluations and quantification of associated uncertainties. Full proceedings and a summary report of the workshop have been released as an OECD/NEA document [7].

A benchmark exercise was undertaken by WGAMA to investigate the current state of the art on fast running methods and tools for predicting the accident source term of radioactive releases and resulting public doses and to promote international cooperation in future development of such tools [8]. The project has demonstrated that the know-how for performing such fast, inevitably approximate accident modeling is quite advanced, benefitting from the mature understanding of the accident phenomenology, software and hardware advances as well as previous development effort in several organizations. Nevertheless, it has been shown that setting up even a relatively simple model to perform accident progression assessment may be a complicated task, especially if dealing with not-so-familiar reactor technology. The spread in predictions is substantial, explained by the varying capabilities of the tools, as well as by the assumptions made by the project participant regarding the possible accident progression. Based on the project results [8], several recommendations for future studies have been offered.

A State-Of-the-Art Report (SOAR) on molten corium concrete interaction and coolability was completed and will be released in 2016 by a working group of the WGAMA of the OECD/NEA [9]. In the SOAR, the working group concerted vision of the phenomenology of core-concrete interactions and melt coolability is summarized together with a global overview of simulation codes capabilities and validation status. This concerted vision demonstrates the significant progresses made on the level of understanding regarding MCCI behaviour under both wet and dry cavity conditions but also led the working group to identify a few issues (particularly based on lessons learned from Fukushima Daiichi situations) that may warrant further investigation to reduce residual uncertainties. These issues include specific realistic reactor conditions from the short to the long term and proposition to improve top flooding melt coolability.

3. ONGOING ACTIVITIES

In this section an overview of well-advanced activities is given. As no specific report has been officially approved by NEA/CSNI a detailed technical description cannot be made. Five activities in total are described below: the THICKET-4 course, the CFD4NRS-6 workshop, the GEMIX benchmark, the review of long-term management and actions for a severe accident, the technical opinion paper on ex-vessel steam explosions and the status report on informing severe-accident management guidance & actions.

THICKET-4 is the fourth edition of a course for transferring competence, knowledge and experience gained through CSNI activities in the field of thermal-hydraulics. The seminar organisation builds on the experience gained with the THICKET courses conducted in 2004, 2008 and 2012. The objective is to transfer to specialists unfamiliar with CSNI activities, and to newcomers in the field, competence and experience acquired from activities carried out in the framework of CSNI during the last two decades, e.g., state-of-the-art reports, computer-code validation matrices, studies of uncertainty quantification, International Standard Problems, specialist workshops, etc. This is felt by WGAMA to be necessary since many achievements of the CSNI in the thermal-hydraulic field have been documented in diverse reports over a long period making it difficult for individuals to reach a coherent overall picture of current knowledge and technology.

THICKET-4 was hosted by MTA EK in Budapest in June 2016 supported by the NEA Secretariat (see http://workshops.energia.mta.hu/thicket-4/). Thirty attendees from 12 countries attended the course and provided a rather positive feedback concerning the course quality (Fig. 2).

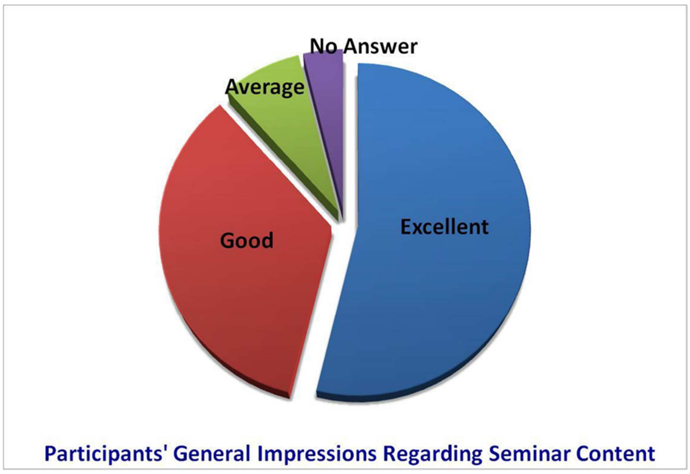

Fig. 2.Results of the THICKET-04 satisfaction query

The CFD4NRS-6 is the sixth edition of a biennial workshop that started in 2006 devoted to the use, development and validation of computational fluid dynamics (CFD) and computational multi-fluid dynamics (CMFD) for nuclear safety analyses. Experiments relevant to nuclear safety that offer CFD-quality data, i.e., local measurements using multi-sensor probes, laser-based techniques, hot-film/wire anemometry, digital imaging, etc., are also a key topic. The context of this WGAMA activity is recognition of the fact that a number of important thermal-hydraulic phenomena cannot be satisfactorily predicted using traditional thermal-hydraulic system codes. Hence, the last two decades have seen increased use of 3D CFD and CMFD simulations in support of nuclear reactor technology. However, CFD codes contain empirical models for simulating turbulence, heat transfer, multi-phase interaction and chemical reactions and such models must be thoroughly validated against experimental data before they can be used with confidence in nuclear applications. This validation must be based on comparison of predictions with trusted data. Furthermore, reliable model assessment requires CFD simulations to be undertaken with clear user guidelines and full control over numerical errors and input uncertainties (see https://www.oecd-nea.org/nsd/csni/cfd/).

CFD4NRS-6 was hosted by the Massachusetts Institute of Technology in September 2016 supported by the NEA Secretariat (see http://cfdr.mit.edu/). A total of 58 papers along with 4 keynote lectures and a plenary talk were presented during the workshop, which was attended by more than 125 researchers and engineers.

The GEMIX benchmark on uncertainty quantification (UQ) in CFD analyses constitutes the first of its kind in the world. The main objective is to compare and evaluate different UQ methodologies currently used to assess the reliability of CFD simulations in the presence of several sources of uncertainties. Benchmark participants contributing CFD analyses were free to choose the uncertainty sources (e.g. boundary conditions, turbulence model coefficients and numerical errors) and the methodology to calculate uncertainty bands. The selection of numerical schemes, turbulence models and computational mesh were also left to participants' discretion. The exercise is based on performing analyses for several experiments (one of which is blind to benchmark participants) performed in Paul Scherrer Institut's GEMIX facility (see https://www.psi.ch/teg/facilities#GEMIX) which investigates the mixing of two flows of different density (Fig. 3). At the time of writing the analyses have been completed and comparisons are being prepared. A few preliminary observations have been already done but they are still under discussion. Nonetheless, the most important conclusion from this exercise is probably the fact that uncertainty quantification is feasible and practicable in CFD analyses for nuclear reactor safety.

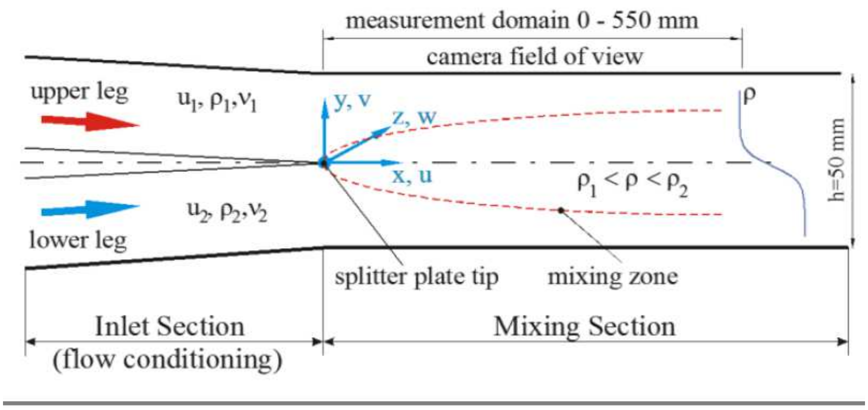

Fig. 3. Conceptual schematics of the GEMIX test

Following the accident at the Fukushima Daiichi NPP, one of the imperatives for the nuclear science and industry communities is to reassess the safety of existing NPPs, notably to evaluate the sufficiency of technical means and administrative measures addressing the management of an accident for the design basis, the beyond design basis, the emergency response and the long term post-emergency phases. Up to now, international actions primarily addressed lessons learnt from the Fukushima-Daiichi accident for the management of short-term phases (EOP and SAMG domains) and for emergency preparedness but the long term accident management and actions (LTMA) were not examined in detail. Therefore, OECD/NEA decided to launch in 2014 an action to (1) review the experience gained for LTMA from the TMI-2, Chernobyl and Fukushima-Daiichi accidents (2) review envisaged, planned or existing regulations, guidance and practices in OECD countries for LTMA for a SA in a NPP (3) describe possible approaches for LTMA (4) identify main risks and issues to be tackled for LTMA and related knowledge gaps (5) provide guidance for enhancing LTMA for a severe accident and (6) make recommendations for future studies and research, including the development or improvement of methods to assess LTMA. Among the technical issues presently being covered one may mention: management of damaged fuel on the long term (inside the reactor vessel and containment as well as in SFP) up to its disposal; strategies for liquid and atmospheric releases mitigation on the long term; treatment and management of liquid, gases and solid wastes; management of the hydrogen risk on the long term; survivability and failure risks of equipment, systems and structures required for maintaining the plant in a safe stable state on the long term; instrumentation required for monitoring LTMA; effect of short-term actions undertaken for the crisis management on the LTMA.

Guidance for enhancing LTMA and recommendations for future studies and research are expected to be delivered through a status report on LTMA in 2017. The main pillars of this status report will be the information gathered from TMI-2, Chernobyl-4 and Fukushima as well as alternative approaches, from identifying Plant Damage States (PDS) to using risk-based methods, and MART building (Management Action Ranking Table). At the time this article is being written, there are a number of issues that have been already highlighted as key for the LTMA, among them: water waste management, decontamination of large areas of site's buildings, reactor and spent fuel pools defueling, etc.

The Technical Opinion Paper (TOP) on ex-vessel steam explosions arose in the context of previous conclusions from the OECD SERENA project in 2007 (see https://www.oecd-nea.org/nsd/docs/2007/csni-r2007-11.pdf) that showed prototypical reactor-core melt to have a weak propensity to produce a steam explosion when falling into ex-vessel water in the containment. However, at the same time, WGAMA recognized that changes in national regulatory requirements post-Fukushima in some countries and a desire to have better precision in steam explosion risk assessment led to both additional experiments and the need to review new information in order to make a judgment on whether the current international consensus on steam explosion probability remains valid. This work is near completion and will be probably published by mid 2017.

Through the activity on informing Severe Accident Management Guidance and Actions, WGAMA aims to provide a basis for consistent definitions of concepts of "verification" and "validation" of severe-accident management (SAM) actions and provide examples of several existing practices aiming at ensuring the correctness, usability and efficiency of SAM (e.g., so-called desk-top exercises, analytical simulations, use of simulators, etc.). The result of analytical simulation of SAM actions may help identify gaps or potential weaknesses in the existing SAM guidance and thus help improve or refine it. The status report will present the best and recommended practices regarding the use of analytical simulations as one of the means to validate SAM actions and strategies. Among the upper level conclusions one might include the suitability of the symptom-based approach to severe accident mitigation and the capability of the current tools to help in the definition of accident management; nonetheless, through the discussions held the groups has concluded that a good implementation of any SAM requires a severe accident knowledge level and specific training on the actions to be taken. This work will be published in 2017.

4. JUST STARTING AND POTENTIAL FUTURE ACTIVITIES

Interest is increasing in best-estimate analysis methods using a three-dimensional (3D) analysis capability for nuclear safety evaluations. Most of the recent system-scale thermal-hydraulic codes propose limited prediction capabilities for dealing with 3D thermal-hydraulic phenomena. These codes are not necessarily used for 3D plant analysis with a full appreciation of the limitations of their 3D capabilities. Hence, an activity is ongoing to determine the state-of-the-art simulation capability of system-scale thermal-hydraulic codes in relation to 3D phenomena relevant to nuclear safety. The product will be a state-of-the-art report (SOAR) that will: provide an overview of existing 3D thermal-hydraulic safety issues in nuclear power plants (NPPs); provide an overview of 3D simulation capabilities in systems codes; identify code limitations for NPP applications; identify the validation database for 3D system-scale codes; and propose future activities on experimental and code development aspects. The SOAR is foreseen to be delivered by the end of 2018.

A Phenomena Identification Ranking Table (PIRT) on spent-fuel pool LOCAs (joint WGAMA activity with the CSNI Working Group on Fuel Safety) is underway. Earlier work on a NEA joint experimental project on spent-fuel pool (SFP) accidents [10] and a joint WGAMA-WGFS review of information and code-analysis capabilities in this area [11] has already been published. While it is recognized that SFP accidents are highly improbable, it was subsequently decided that a need exists to review the SFP accident phenomenology to evaluate the importance of particular phenomena with respect to the overall influence on the consequences of SFP accidents. The phenomena identification and ranking table (PIRT) approach has been adopted aiming to identify the most influential phenomena for which the level of knowledge is poor, i.e., in need of research and hence a priority for investigation. To do so both loss of cooling and loss of coolant accidents are being addressed and three phases have been set in the accident unfolding. The traditional approach, used for the first time during the late 80's of last century [12], has been adopted and specific figures of merit have been agreed upon among the participants. This work should be published in 2018 and lead to international consensus on prioritization of research needs with respect to this kind of accident.

Recently, the Committee for the Safety of Nuclear Installations has approved the launch of an activity to prepare the next CFD4NRS-7, which will keep the high technical and scientific standards of previous additions and pay particular attention to the Uncertainty Quantification of CFD simulations.

Additionally, there are some activities that have been compiled as potential future activities but have not been even developed to the first step needed, the preparation of a "CSNI Activity Proposal Sheet" (CAPS). Some of them might concern: safety assessment of passive systems; a workshop on instrument performance in severe-accident conditions; an assessment of by-pass accident source-term; an analysis of plant ageing influence on severe-accident progression/understanding/mitigation; and a code benchmark for SFP LOCA (possible result of the PIRT on phenomena in SFP accidents).

5. FINAL REMARKS

In the sections above, the current status of the WGAMA group of NEA has been outlined by briefly summarizing what has recently finished, what is presently ongoing and what could be launched in the near future. In short, all this highlights that WGAMA is a very active group of NEA who in the very last years has demonstrated an outstanding capability of response, being capable of shaping their activities to the prompt and demanding needs that stem from the Fukushima analysis without neglecting its own idiosyncrasy and way of doing. Beyond how prolific the Group is in terms of Status Report and Status Of the Art Reports (SOAR), the diversity of the Group activities is outstanding, encompassing a broad spectrum from education (THICKET-4) to code benchmarking (GEMIX). The WGAMA commitment to produce technical support to regulatory decision-making process has resulted in a number of ideas that are being presently conceived and will streamline the coming activity of the group in those areas in which WGAMA develops their activities: Thermal-hydraulics, Computational Fluid-Dynamics and Severe Accidents.

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