CONTRIBUTION OF THE OECD/NEA WORKING GROUP ON THE ANALYSIS AND MANAGEMENT OF ACCIDENTS (WGAMA) IN THE SEVERE ACCIDENT FIELD

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Abstract

The Committee on the Safety of Nuclear Installations (CSNI) aims to assist OECD Nuclear Energy Agency (NEA) member countries in maintaining and further developing the scientific and technical knowledge base required to assess and improve the safety of nuclear reactors and fuel cycle facilities. As one of the CSNI working groups, the 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 paper describes some of the major outcomes concerning Severe Accidents WGAMA activities. In total, over 60 reports have been issued since the group creation in the early 2000s, amongst them State-of-the-Art Reports, International Standard Problems and benchmarks. In addition, Workshops have been arranged and also databases have been created. Then, it outlines meaningful contributions that were conducted in response to issues identified after the Fukushima-Daiichi accident. Finally, some information is provided concerning the progress achieved in ongoing activities, like the phenomena identification ranking table on spent fuel pools during LOCAs, informing SAM guidance via simulation, reviewing the major conclusions related to ex-vessel steam explosions in the light of new data and improving long term management of severe accidents in the light of passed major accidents.

1. INTRODUCTION

The Working Group on Analysis and Management of Accidents (WGAMA) is one of eight working groups under 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 fulfill 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.

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; 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 paper outlines the activities within the WGAMA in the severe accident field. 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 running activities.

![Fig.1. Working Groups and Project under the NEA/CSNI framework](image)

2. BRIEF OVERVIEW OF RECENTLY FINISHED ACTIVITIES IN THE SEVERE ACCIDENT FIELD

In the follow-up of the Fukushima Daiichi NPP accident (FDNPs), WGAMA conducted for the CSNI several high priority activities and established status reports on spent fuel pool (SFP) accidents [1], hydrogen management [2], filtered containment venting systems (FCVS) [3] and achieved a benchmark exercise on fast running methods and tools for predicting radioactive releases [4].

The status report on SFP produced a summary of the status on SFP accidents and mitigation strategies to contribute to the post-FDNPs decision making process, provided an assessment of current experimental and analytical knowledge about loss of cooling and LOCA in SFPs and their mitigation strategies, briefly discussed strengths and weaknesses of analytical tools to predict SFP accident evolution and assess the efficiency of cooling mechanisms for mitigation and identified research activities to address gaps in the understanding of relevant phenomenological processes to reduce uncertainties in the analysis of such accidents. It was in particular concluded that more specific modelling for SFPs is desired where current codes are intended mainly for SA analysis (source-term estimation being a challenge) and that it would be valuable to produce specific user guidelines for code applications to SFP accidents. It was also concluded that important uncertainties should be
ranked via a PIRT exercise; such an exercise is currently being conducted through a WGAMA/WGFS (Working Group on Fuel Safety) joint action.

The status report on hydrogen risk management reviewed the various approaches in member countries (approaches in DBAs and SAs including national requirements, mitigation, measurement strategies, engineered systems (sprays, air cooler, blow-out panels, etc.) and potential impact, advantages and consequences of different options) for all water-cooled reactors (PWRs, VVERs, BWRs & PHWRs). The report also addressed capabilities and validation status of dedicated codes. It was identified that further efforts are needed to close research gaps, enhance code capabilities and reduce code uncertainties. Assessment is needed of how knowledge gained from research has been implemented in NPP safety analysis and how it is considered in SAMG. In particular, pressure loads due to H₂ and/or CO combustion on containment and equipment (especially where this is safety related) need to be further assessed particularly for ex-vessel conditions where this may be plant specific.

The status report on FCVS compiled the status of implementation of FCVS in reactors in OECD countries, the national requirements for systems designs and filter performance, the various venting strategies as well as advantages and disadvantages of containment venting. It also described briefly installed systems and their demonstrated and expected performances. Further, possible improvements for hardware (particularly filtration) and qualification of the systems were identified from an accident management perspective. The report was produced as a guide for decision makers in regulatory authorities, technical support organizations, research institutes and utilities which consider FCVS implementation.

The benchmark on fast running methods and tools for predicting the accident source term of radioactive releases and resulting public doses has demonstrated that the know-how for performing such fast, inevitably approximate accident modelling 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 evidenced 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 was shown to be 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, several recommendations for future studies have been offered for promoting international cooperation in future development of such tools. These recommendations helped in elaborating the European FASTNET project which is currently underway and aims at improving diagnosis and prognosis methods and tools for emergency response.

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 their 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 [5]. They mostly concern the necessity 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, containment and solid filters surfaces and from pools (sumps, suppression pools, liquid pools in filters) on source term evaluations;
- 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 report [5].

A State-Of-the-Art Report (SOAR) on molten corium concrete interaction (MCCI) and coolability was completed and will be released in 2017 [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 progress 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 configurations (as illustrated in Fig. 2) from the short to the long
term and proposition to improve top flooding melt coolability. Further relevant experimental investigations will require technological updates of existing facilities.

Fig. 2. Schematic representation of a realistic reactor configuration during MCCI

3. ON-GOING ACTIVITIES IN THE SEVERE ACCIDENT FIELD

A Phenomena Identification Ranking Table (PIRT) on spent-fuel pool LOCA is underway. Earlier work on a NEA joint experimental project on spent-fuel pool (SFP) accidents [7] and review of information and code-analysis capabilities in this area [1] has already been published and it was recognized that a need existed 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 (phase 1 up to start of fuel assembly de-watering, phase 2 up to cladding rupture, phase 3 addressing fuel degradation). This work should be published in 2018 and lead to international consensus on prioritization of research needs with respect to this kind of accident. The SFP accident scenarios have been observed to be extremely complex and despite the more than 100 phenomena of potential influence in accident evolution, PIRT contributors have found the way to boil down this list to less than 10 phenomena.

A Technical Opinion Paper (TOP) on ex-vessel steam explosions is being written in the context of previous conclusions from the OECD SERENA project [8] and more recent results that showed melts to have a propensity to produce steam explosions when falling into shallow layers of water [9]. At the same time, WGAMA recognized that changes in national regulatory requirements post-FDNPs in some countries and a desire to have better precision in steam explosion risk assessment led to both additional experiments in some countries and the need to review new information in order to make a judgment on whether the current approaches to steam explosion risk management remain valid. This work is near completion and should be published early 2018. It demonstrates that significant progress was made in the understanding of phenomena involved in steam explosion but that further investigations are still needed to adequately appreciate the risk of safety components and structures failure due to steam explosion. It was thus recommended to perform further experimental investigations of specific realistic reactor configurations and more fundamental investigations of the fragmentation, oxidation, solidification and pressurisation processes to improve the corresponding modelling in dedicated codes.

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 2018. The main pillars of this status report will be the information gathered from TMI-2, Chernobyl-4 and Fukushima (as illustrated in Figure 3) 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.

![Fig. 3. Insights from TMI-2 and Chernobyl accidents for LTMA](image)

Through the activity on informing Severe Accident Management Guidance and Actions, WGAMA aimed 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. 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.
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: 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 updates of state of the art reports on FP release and transport.

4. CONCLUDING 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 FDNPs 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 to code benchmarking. 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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