EDITORIAL

ERMSAR-2019 conference of NUGENIA TA2/SARNET on research on severe accidents in nuclear power plants

Nuclear safety has been improved continuously over years. Nonetheless, despite the most recent safety features and the accident prevention measures adopted in current nuclear power plants (NPP), some very low probability accidental sequences may develop into severe accidents and result in core melting and plant damage. If not mitigated, these accidents might potentially lead to radioactive materials dispersal outside the nuclear power plant and become a hazard for the public health and for the environment.

In the framework of the 6th and 7th EU Research and Development Framework Programmes (FP6 and 7) the SARNET network of excellence (Severe Accident Research NETwork) was launched in 2004 and co-funded by the European Commission until mid-2013. The aim of this excellence network was to better coordinate the national efforts in Europe, optimising the use of the available expertise and of the experimental facilities, to resolve the remaining main open issues for enhancing the safety of existing and future European NPPs. This network consolidated a sustainable integration of the European research capacities for severe accident and achieved a significant progress, in collaboration with the main worldwide organizations involved in the field (Van Dorsselaere at al., 2015). In mid-2013, SARNET was fully integrated in the NUGENIA European association (see www.nugenia.org) that addresses R&D on Generation II and III NPPs. The SARNET activities have continued inside the NUGENIA Technical Area N°2 (TA2), “Severe Accidents”, initially with the coordination by IRSN and - from December 2018 - by CIEMAT. This TA2 extends the former network activities to the new issues of “emergency and preparedness response” and “severe accident impact on the environment”, emphasizing even further the search for more efficient and innovative mitigation measures which has focused most of research since the Fukushima Daiichi accident. The main TA2/SARNET activities currently addressed are:

- Update of research priorities;
- proposal and development of new R&D projects under different frameworks;
- organization of periodic conferences, known as the European Review Meeting on Severe Accident Research ERMSAR (Van Dorsselaere and Paci, 2014, Van Dorsselaere and Paci, 2016, Van Dorsselaere and Paci, 2018);
- organization of education and training courses, the last one held in September 2019, hosted by the CEA in Cadarache (F).

The 9th ERMSAR conference, which selected papers are gathered in this Annals of Nuclear Energy special issue, was hosted by the ÚJV Řež in Prague (Czech Republic) from 18 to 20 March 2019. The Scientific Programme Committee involved eight researchers from diverse organizations (CEA, CIEMAT, ENEA, IAEA, IRSN, JSI and University of Pisa). The conference gathered 163 participants from 23 countries and 73 organizations (19% of participants came from out of Europe such as Canada, Egypt, India, Japan, USA, China, and Republic of Korea), confirming its status as a major international event in nuclear reactor safety. Sixty-five papers plus several posters were presented in the 3 days and a significant time was allocated after each presentation for questions and open discussions.

During the plenary introductive session, after the ÚJV general presentation and the overview of NUGENIA TA2/SARNET activities by CIEMAT, three invited papers addressed the research activities related to safety of Czech NPPs by CEZ a.s., the SA modelling evolution in US by SNL and Current status and recent investigation result of Fukushima Daiichi by TEPCO. Three other invited papers were also dedicated to the International programs presented respectively the EC H2020, the OECD/NEA and the IAEA Projects on Severe Accidents.

Seven sessions were organized during the conference:

1. In-vessel corium and debris coolability
2. Emergency management and severe accident impact on the environment
3. Severe accident scenarios
4. Severe accident modelling and code development
5. Source term issues
6. Ex-vessel corium interactions and coolability
7. Containment behaviour including hydrogen explosion risk

All these 7 topics included both experimental and modelling activities, as well as the assessment of the applicability of simulations to real plant scenarios, and the main high-priority topics of the NUGENIA R&D roadmap have been addressed.

This virtual special issue (VSI) of Annals of Nuclear Energy journal includes an extended and upgraded version of the best 12 papers that were selected by the Scientific Programme Committee of ERMSAR 2019 (all papers presented during ERMSAR 2019 are available on the Conference website www.ermsar2019.com).

Session I “in-Vessel Corium and debris coolability” (18 papers)

The R&D in this domain aims at the reduction of the remaining uncertainties on the possibility of cooling the reactor core structures during a severe accident, either in the core region or inside the vessel lower head, to limit the progression of the accident. This goal could be achieved either by ensuring the retention and the cooling of the corium within the reactor vessel by a water injection or, at least, a slow corium progression and small flow rates for the corium release into the containment cavity. These issues are linked to severe accident management (SAM) for the current reactors and for the design and safety evaluation of future NPPs.

The 3 following papers that addressed the corium behaviour in the vessel lower head or the In-Vessel-Melt-Retention (IVMR) were selected for this VSI:

- “CoreSOAR Core Degradation State-of-the Art Report Update: Conclusions” by T. Haste et al. (IRSN)
- “Main outcomes from the IVR code benchmark performed in the IVMR project” by L. Carenini et al. (IRSN)
- “Elaboration of a PIRT for the modelling of In-Vessel Retention” by F. Fichot et al. (IRSN)

The first one presented the CoreSOAR project, in NUGENIA/SARNET, drawing together the experience of 11 European partners to update the state of the art in core degradation. This review covered knowledge of phenomena, available integral experiments, separate-effects data, modelling codes and code validation, then drawing overall conclusions and identifying needs for further research.

In the second paper, the main outcomes of a benchmark exercise for code validation in the European H2020 project IVMR (In-Vessel Melt Retention) were presented. It was based on the definition of different IVR configurations at reactor scale with an increase in the complexity of the phenomena involved. Thanks to the approach followed with a progressive increase of complexity, the capabilities of these codes to evaluate the heat flux profile applied to the vessel wall in steady state were demonstrated.

In the last paper of this section I presents the development, inside the H2020 European project IVMR (In-Vessel Melt Retention) addressing the issue of selecting and improving IVR models for safety evaluation, of a Phenomena Identification Ranking Table (PIRT) involving the relevant IVR physical processes. The main outcome of this PIRT was that significant tendencies can be observed and allow the identification of the uncertainties and of the phenomena/variables with the highest (or lowest) importance.
Session II “Emergency management and severe accident impact on the environment” (4 papers)

In this quite small session the only paper selected “SOARCA Uncertainty Analysis of a Short-Term Station Blackout Accident at the Sequoyah Nuclear Power Plant” by N. Bixler (SNL) presents the US-NRC state-of-the-art reactor consequence analyses (SOARCA) project about realistic estimates of the offsite radiological health consequences for potential severe reactor accidents. Accident progression calculations used the MELCOR code and offsite consequence analyses were performed with MACCS. The analysis included more than 500 MELCOR and MACCS simulations to account for uncertainty in important accident progression and offsite consequence input parameters.

Session III “Severe accident scenarios” (16 papers)

Most papers in this session presented the prediction capabilities of computer integral codes (mainly MAAP and MELCOR) as well as the evaluation of SAM procedures. A majority focused on modelling of in-vessel phenomena and corium propagation in PWR or BWR.

The 2 following papers have been selected for this VSI:
- “Challenges and sensitivities in the modelling of Fukushima Unit 1 unfolding with MELCOR 2.2” by Luis E. Herranz, Claudia López (CIEMAT)

The first paper throughout an analysis of the challenges posed by the Fukushima Unit 1 data recorded, describes the major postulates proposed by CIEMAT concerning the equipment and component responses, the effectiveness of accident management actions and the MELCOR model applied. Open issues still requiring investigation are also highlighted.

About the second selected paper, the US NRC has completed three uncertainty analyses (UAs) as part of the State-of-the-Art Reactor Consequence Analyses (SOARCA) program, including an integrated evaluation of uncertainty in accident progression, radiological release, and offsite health consequence projections. This paper provides a high-level summary of these three SOARCA UAs and some of the most important insights that will be captured in a future summary technical report.

Session IV “Severe accident modelling and code development” (6 papers)

No paper has been selected for this session IV where only 6 papers have been presented but other presentations related to severe accident code status were however in ERMSAR 2019 program. To be highlighted from the papers of this section was the increasing attention to Uncertainties Analysis.

Session V “Source Term issues” (9 papers)

Most of the papers in this session focused on the mitigation of source term and on the fission product chemistry. The main emphasis was on iodine and ruthenium nuclides, given their high radio-toxicity and volatility.

The 2 selected papers for this journal’s VSI special issue addressed the quantification of the remaining uncertainties on the source term, confirming the growing interest in UA also in this field:
- “Uncertainty quantification of in-pool fission product retention during BWR Station Black Out sequences” by Luis E. Herranz et al. (CIEMAT)
- “Review of knowledge and remaining uncertainties on potential sources of organic iodides in a NPP containment during a severe accident” by L. Bosland, J. Colombani (IRSN)

The first paper investigates how uncertain predictions of suppression pools decontamination can be. Based on MELCOR 2.2 calculations of Fukushima Unit 1, a stand-alone version of SPARC-90 (Suppression Pool Aerosol Removal Code) was employed in combination with DAKOTA-6.4, to propagate the uncertainties in the input deck variables affecting the Decontamination Factor (DF). The results indicate that DF uncertainties may spread around two orders of magnitude and the uncertainty margin stays roughly constant over time.

In the second paper, a review of the knowledge of chemical mechanisms leading to organic iodides (RI) formation and decomposition and the remaining uncertainties was performed. As outcome of it, recommendations concerning still necessary experimental investigation were made.

Session VI “Ex-Vessel Corium interactions and coolability” (7 papers)

The investigated accidental situation, after a postulated failure of the lower head of the reactor pressure vessel, is the corium presence in a reactor cavity that is initially dry but with the possibility of a water injection later on during the molten-core-concrete-interaction (MCCI). Furthermore, steam explosions may be caused by the fuel-coolant-interaction (FCI) after the corium pouring into a flooded reactor cavity.

Most of the presented papers addressed FCI and debris coolability. Among them, the 2 following papers were selected for the present VSI:

- “Impact of Corium Thermophysical Properties on Fuel-Coolant Interaction” by C. Brayer, et al. (CEA Cadarache)
- “Retrofitting of a Generic Ex-Vessel Core Catcher for the Safety Improvement of Operating Nuclear Power Plants, at the Example of a BWR with Mark I Containment” by M. Fischer, T. Keim (Framatome GmbH)

The aim of the first paper is to assess the impact of corium thermophysical properties on fuel-coolant interaction. The phenomenology of FCI, together with the main correlations introducing the corium thermophysical properties, are presented together with the presentation of the Morris methodology and the definition of property variation range according to the literature or to model prediction. The results of MC3D calculations are also presented, highlighting the important role played by the corium surface tension on the progression of the FCI.

The second paper initially provides an overview of the applicable technical solutions for the core melt stabilization (CMS) concepts with respect to their suitability for Gen-II retrofitting, including their specific benefits and disadvantages, then lists the typical functional requirements and limitations and shows which ex-vessel solutions have the highest potential and are currently considered or used for retrofitting. Finally the results of a screening of available melt stabilization solutions for an exemplary Mark-I BWR containment are given.

Session VII “Containment behaviour including hydrogen explosion risk” (5 papers)

The R&D focus in this scientific domain is on the threats to the containment integrity caused by highly energetic phenomena, particularly the hydrogen combustion. Hydrogen combustion (deflagration and detonation) may be caused by the ignition of a gas mixture characterized by high local hydrogen concentrations, which may be due to the imperfect mixing of the containment internal atmosphere.
Few papers were presented in this Session VII, contrary to the previous ERMASAR Conference, mainly on analysis of THAI experiments and behaviour of passive auto-catalytic recombiners (PAR), but two papers have been selected, both about the PAR poisoning due to carbon monoxide:

- “Measurements of the Impact of Carbon Monoxide on the performance of Passive Autocatalytic Recombiners at Containment-typical Conditions in the THAI Facility” by M. Freitag et al. (B-T GmbH)
- “Effect of PAR deactivation by carbon monoxide in the late phase of a severe accident” by E.-A. Reinecke et al. (FZJ GmbH)

The first one is about an experimental test series under containment typical boundary conditions performed in the THAI-facility to investigate the PAR performance under the presence of carbon monoxide while, in the second paper, a COCOSYS accidents simulation predicts that the PARs in relevant containment regions will stop operation for poisoning. Therefore, the hydrogen concentration reaches significantly higher values at the end of the calculated scenario when compared with calculations without taking into account PAR poisoning.

Conclusions and NUGENIA TA2/SARNET perspectives

The NUGENIA TA2/SARNET activities are continuing but with a reorientation from pure knowledge-based R&D towards R&D for prevention and mitigation of severe accident consequences (as already underlined by on-going EURATOM projects that are linked to NUGENIA TA2). However, for the future, the usability of the obtained R&D results must be analysed and the remaining uncertainties properly identified and quantified, before addressing any major research project. One recommendation for the next ERMSAR conference was the request of a specific PSA2 session.

Furthermore an updated of the NUGENIA R&D roadmap is expected in the next months, basing also on the ERMSAR 2019 conclusions, for the updating of the research priority ranking, initially defined in 2013 inside SARNET.

ERMSAR is still fully active 14 years after the 1st conference in 2005 in Aix-en-Provence (France) and, after these 9 events, it has achieved worldwide recognition and credit among researchers and engineers involved in severe accidents. The fact of having a large number of young researchers present in Prague, together with a good number too of "credited senior experts", made ERMSAR-2019 an excellent exchange and networking forum which should be further reinforced in future using the specific mobility actions foreseen for example in the EU Projects as MUSA.

Karlsruhe Institute of Technology (Germany) will host the 10th ERMSAR conference in spring 2021.

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References


