

## ERMSAR-2022 conference “Severe accident research: Eleven years after the Fukushima accident”

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 accidents with the damage of the nuclear fuel and result in core melting. If not mitigated, these sequences (known as “severe accidents” and, more recently, referred to as Design Extension Conditions accidents type B, DEC-B) might potentially lead to a release of radioactive materials outside the plant and become a significant hazard for the public health and for the environment. This risk can be substantially decreased when state-of-the-art devices currently available for prevention and mitigation of severe accidents are installed. Lessons from the Fukushima-Daiichi accidents and consequences related to Accident Management (AM) provisions from the ENSREG (European Nuclear Safety Regulators Group) stress tests and other national activities lead to further enhancement of the safety of NPPs.

In the framework of the past 6th and 7th EU Research and Development Framework Programmes (FP6 and FP7), to better coordinate the national efforts in Europe in the severe accident research area, to optimize the use of the available expertise and of the experimental facilities, and to resolve the main open issues for enhancing the safety of existing and future European NPPs, the SARNET Network of excellence (Severe Accident Research NETwork) was launched in 2004 and co-funded by the European Commission until mid-2013. This excellence network consolidated a sustainable integration of the European research capabilities for severe accident and achieved a significant progress (van Dorselaere et al., 2015), in collaboration with the main worldwide organizations involved in such nuclear safety field. On mid-2013, the SARNET network was fully integrated into the Nuclear Generation II & III Alliance NUGENIA (see [www.nugenia.org](http://www.nugenia.org)), dedicated to the R&D of nuclear fission technologies, with a focus on safe and efficient operation of Generation II & III NPPs. From 2019 NUGENIA becomes one of the three pillars of the Sustainable Nuclear Energy Technology Platform SNETP (<https://snetp.eu/>), established to support and promote the safe, reliable, and efficient operation of Generation II, III and IV civil nuclear systems.

The different activities on severe accidents have continued inside the NUGENIA Technical Area N°2 (TA2), “Severe Accidents” (van Dorselaere et al., 2017), initially coordinated by IRSN Cadarache and – from December 2018 – by CIEMAT Madrid. The NUGENIA TA2 extends the former SARNET network activities over 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 for such a kind of severe sequences, which has focused most of the research since the Fukushima Daiichi

accident (Herranz et al., 2020a).

The main NUGENIA TA2 activities currently addressed are:

- Update of the priorities for the European research in the severe accident area, starting from the conclusion on Severe Accident Research Priorities (SARP) by the workgroup inside SARNET network (Klein-Heßling et al., 2014).
- Proposal and development of new R&D projects under different frameworks, as shown in the NUGENIA TA2 Project Portfolio <https://snetp.eu/project-portfolio/>.
- Organization (from 2005 inside SARNET and from 2017 in NUGENIA TA2) of a series of periodic conferences, known as the European Review Meeting on Severe Accident Research ERMSAR (van Dorselaere and Paci, 2018, 2016, 2014), (Herranz et al., 2020b);
- Organization of education and training courses (Paci and van Dorselaere, 2012) on Severe Accident Phenomenology (SAP), the last one held on-line in October 2021, technically hosted by ENEA Bologna (I).

The last 10th edition of the ERMSAR Conference, whose most relevant papers selected by the conference Technical Committee are collected in this Special Issue “ERMSAR 2022 Conference: Severe Accident Research Eleven Years after the Fukushima Accident”, was successfully held in hybrid format from 16 to 19 May 2022 in Karlsruhe, hosted and locally organized by the Karlsruhe Institute of Technology (KIT), after 3 years for the previous 2019 edition in Prague. For the fourth time, it has been organized in the frame of NUGENIA TA2 and, for the first time, in collaboration with IAEA and OECD/NEA. The Technical Programme Committee involved 18 researchers from diverse organizations and agencies (BT-Becker Technologies, CEA, CIEMAT, ENEA, Framatome GmbH, GRS, IAEA, INRN, IRSN, JSI, KIT, KTH, NEA and University of Pisa).

ERMSAR 2022 gathered 118 participants (more than 100 in presence) from nearly 50 organizations settled in 21 countries worldwide (EU, USA, Republic of Korea, Brazil, Japan, India), which highlights ERMSAR as the reference international conference on severe accidents. Sixty papers were orally presented and 9 more were exhibited in the posters stand, among which is worth noting there were two posters submitted by Ukrainian colleagues from the ES Group LLC (Kiev).

In addition, the ERMSAR 2022 technical programme included three plenary sessions, in addition to a specific presentation on the NUGENIA TA2 latest activities and status:

- Overview of the international programmes on severe accident research (contributions from European Commission, NEA and IAEA).
- Fukushima, from the understanding to accident management and decommissioning (NEA, TEPCO and JAEA/CLADS).
- Round table on new elements in the severe accident research domain (Accident Tolerant Fuels ATF by Energy Research Inc., Small Modular Reactors SMR by TRACTEBEL, Environmental impact by KIT, and Modelling innovation by IRSN).

The conference, traditionally open to both NUGENIA and non-NUGENIA members, was focused on the latest progress of international knowledge on severe accidents and has been mainly an opportunity for researchers to discuss, finally in presence after two years of sanitary emergency, about the future R&D priorities in this field. The ERMSAR 2022 was structured in a number of topics that resulted in the following list of the technical sessions:

- 1 In-vessel corium and debris coolability
- 2-1 Severe accident scenarios
- 2-2 Uncertainties in severe accident scenarios
- 3 Ex-vessel corium interactions and coolability
- 4 Severe accidents scenarios in innovative systems
- 5 Source term
- 6 Severe Accident Modeling and Code Development
- 7-1 Hydrogen and Containment Related issues
- 7-2 Containment Behaviour – Recombination

It is worth noting that this edition ERMSAR scope enlarged with respect to previous ones, including a specific session on uncertainties in severe accident simulations and addressing innovative systems in another one.

To encapsulate and preserve all this expertise, an open book of the Proceedings of the Conference has been published (Gabielli et al., 2022), which contains the presented papers, presentations, and posters. As of today, this book is available for the free download from the KITopen Repository at <https://publikationen.bibliothek.kit.edu/1000151444>.

It is worth to highlight that some new R&D needs brought up during the ERMSAR 2022 presentations, are currently being addressed by three recently born European Union supported Projects inside the NUGENIA TA2 (Horizon Europe):

- ASSAS, for the possible Artificial Intelligence (AI) application in severe accident simulations, developing a proof-of-concept severe accident simulator.
- SEAKNOT, for severe accident knowledge management, its preservation and transfer to young generation of researchers, mainly to efficiently orient the forthcoming European research on severe accidents in next decade.
- SASPAM-SA, for the application of current severe accident grounds to near-term SMRs, mainly integral Pressurized Water Reactor (iPWR), in the view of the European licensing analyses needs for Severe Accidents and Emergency Planning Zone.

Both ERMSAR-2022 and these three EU-funded projects demonstrate how “alive” and “healthy” is severe accident research. Of course, additional experimental and theoretical investigations are on-going in other European-supported (Horizon-2020) projects: MUSA (Herranz et al., 2021)), R2CA (Girault et al., 2022) and AMHYCO (Jiménez et al., 2021).

As major conclusions from ERMSAR 2022 it is also possible to highlight:

- A good part of nuclear R&D will continue investigating on Severe Accident Mitigation (SAM), in particular on feasibility and development of “new” mitigation measures.

- A strong orientation towards very near-term deployment systems, like SMRs, with a major take on “safety demonstration” and current analytical tools drawbacks for “very innovative” systems has been settled for the coming years. Additionally, it will be necessary to identify experimental data needs in pursuing the aim of studying non-LWR designs and, in the longer term, the Verification and Validation (V&V) of codes for the licensing of such new systems.
- Efforts should be also oriented to widen the range of applicability of the severe accident codes both to Gen IV technologies and to further improve the modelling of specific components in deployed systems. It is also considered timely to soundly set of severe accident research needs and priority towards new technologies, e.g., SMRs or ATFs, and find the best use possible in the area of AI/machine learning, with the focus on safety-relevant phenomena (“risk informed”).

In the closing session of the Conference, the next edition ERMSAR 2024 was announced to be organized by KTH in Stockholm on May 13–16, 2024 in the frame of the new SEAKNOT project, founded by EU. *This ERMSAR 2022 edition was in memory of Martin Kissane.*

Luis E. Herranz (CIEMAT Madrid, Spain), NUGENIA TA2 coordinator  
Fabrizio Gabrielli (KIT, Germany), local organizer of the ERMSAR 2022 conference

Sandro Paci (University of Pisa, Italy), responsible for spreading of excellence activities in NUGENIA TA2

## Acknowledgements

All the actors of the ERMSAR-2022 conference must be acknowledged, in particular the KIT support team, especially Mrs. Petra Klug, Mrs. Ingeborg Schwartz, Mrs. Isabelle Windbiel, Mr. Simon Scheuerle for taking care of the organizational-technical matters, and the Scientific Programme Committee: besides the guest editors below, Ahmed Bentaib from IRSN (France), Sanjeev Gupta from BT (Germany), Pascal Piluso from CEA (France), Federico Rocchi from ENEA (Italy), Ivo Kljenak from JSI (Slovenia) and Alexei Miasoedov from IAEA (Austria). Finally, this special issue would not have been possible without the assistance of the Elsevier staff.

## References

- Gabielli, F., Herranz, L.E., Paci, S., 2022. Proceedings of the 10th European Review Meeting on Severe Accidents Research (ERMSAR2022): Severe Accident Research Eleven Years after the Fukushima Accident. Karlsruhe Institut für Technologie (KIT), Karlsruhe.
- Girault, N., Mascari, F., Kaliatka, T., 2022. The R2CA project for evaluation of radiological consequences at design basis accidents and design extension conditions for lwr: motivation and first results, in: Proceedings of the 10th European Review Meeting on Severe Accidents Research (ERMSAR2022) May 16-19, 2022. Karlsruhe Institut für Technologie (KIT), pp. 1–12.
- Herranz, L.E., Duspiva, J., Paci, S., 2020b. ERMSAR 2019 conference of NUGENIA TA2/SARNET on research on severe accidents in nuclear power plants. *Ann. Nucl. Energy* 139, 107235.
- Herranz, L.E., Beck, S., Sánchez-Espinoza, V.H., Mascari, F., Brumm, S., Coindreau, O., Paci, S., 2021. The EC MUSA project on management and uncertainty of severe accidents: main pillars and status. *Energies* 2021 (14), 4473. <https://doi.org/10.3390/EN14154473>.
- Herranz, L.E., Bentaib, A., Gabrielli, F., Gupta, S., Kljenak, I., Paci, S., Piluso, P., Rocchi, F., 2020a. NUGENIA/TA2 Achievements in Severe Accidents Research (2015-2020). Nuclear Espana.
- Jiménez, G., Herranz, L.E., Bentaib, A., Djebaili-Chaumeix, N., Reinecke, E.A., Kelm, S., Loeffler, M., 2021. AMHYCO Project – Towards Advanced Accident Guidelines for Hydrogen Safety in Nuclear Power Plants, in: International Conference on Hydrogen Safety. Hydrogen Knowledge Centre.
- Klein-Hefling, W., Sonnenkalb, M., Jacquemain, D., Clément, B., Raimond, E., Dimmelmeier, H., Azarian, G., Ducros, G., Journeau, C., Herranz Puebla, L.E., Schumm, A., Miasoedov, A., Kljenak, I., Pascal, G., Bechta, S., Guntay, S., Koch, M. K., Ivanov, I., Auvinen, A., Lindholm, I., 2014. Conclusions on severe accident research priorities. *Ann. Nucl. Energy* 74, 4–11. <https://doi.org/10.1016/j.anucene.2014.07.015>.
- Paci, S., Van Dorsselaere, J.-P., 2012. Spreading of excellence in SARNET network on severe accidents: The education and training programme. *Sci. Technol. Nucl. Install.* 2012, 1–9.
- van Dorsselaere, J.-P., Brechignac, F., de Rosa, F., Herranz, L.E., Kljenak, I., Miasoedov, A., Paci, S., Piluso, P., 2017. Trends in severe accident research in

- Europe: SARNET network from Euratom to NUGENIA. *EPJ Nucl. Sci. Technol.* 3, 28. <https://doi.org/10.1051/EPJN/2017021>.
- Van Dorsselaere, J.-P., Paci, S., 2014. ERMSAR 2013 conference of the SARNET network. *Ann. Nucl. Energy* 74, 1–3.
- Van Dorsselaere, J.-P., Paci, S., 2016. ERMSAR-2015 conference of SARNET in the frame of the NUGENIA Technical Area 2. *Ann. Nucl. Energy* 93, 1–3.
- Van Dorsselaere, J.-P., Auvinen, A., Beraha, D., Chatelard, P., Herranz, L.E., Journeau, C., Klein-Hessling, W., Kljenak, I., Miasoedov, A., Paci, S., Zeyen, R., 2015. Recent severe accident research synthesis of the major outcomes from the SARNET network. *Nucl. Eng. Des.* 291, 19–34.
- Van Dorsselaere, J.-P., Paci, S., 2018. ERMSAR-2017 conference of NUGENIA/SARNET on research on severe accidents in nuclear power plants. *Ann. Nucl. Energy* 118, 414–416.

Luis E. Herranz  
*CIEMAT, Spain*

Fabrizio Gabrielli  
*KIT, Germany*

Sandro Paci  
*University of Pisa, Italy*