IAEA
International Atomic Energy Agency

PROCEEDINGS SERIES

# Topical Issues in Nuclear Installation Safety

## Strengthening the Safety of Evolutionary and Innovative Reactor Designs

PROCEEDINGS OF AN INTERNATIONAL CONFERENCE
Vienna, Austria, 18–21 October 2022

European Commission
ETSON
NEA NUCLEAR ENERGY AGENCY
WORLD NUCLEAR ASSOCIATION

# TOPICAL ISSUES IN NUCLEAR INSTALLATION SAFETY

The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world''.

PROCEEDINGS SERIES

# TOPICAL ISSUES IN NUCLEAR INSTALLATION SAFETY

## STRENGTHENING THE SAFETY OF EVOLUTIONARY AND INNOVATIVE REACTOR DESIGNS

PROCEEDINGS OF AN INTERNATIONAL CONFERENCE ORGANIZED BY THE
INTERNATIONAL ATOMIC ENERGY AGENCY
IN COOPERATION WITH
THE EUROPEAN COMMISSION JOINT RESEARCH CENTRE,
THE EUROPEAN TECHNICAL SAFETY ORGANISATIONS NETWORK,
THE OECD NUCLEAR ENERGY AGENCY
AND THE WORLD NUCLEAR ASSOCIATION
AND HELD IN VIENNA, 18–21 OCTOBER 2022

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2025

Printed by the IAEA in Austria
March 2025
STI/PUB/2108

**IAEA Library Cataloguing in Publication Data**

Names: International Atomic Energy Agency.
Title: Topical issues in nuclear installation safety : strengthening the safety of evolutionary and innovative reactor designs / International Atomic Energy Agency.
Description: Vienna : International Atomic Energy Agency, 2025. | Series: Proceedings series (International Atomic Energy Agency), ISSN 0074–1884 | Includes bibliographical references.
Identifiers: IAEAL 25-01740 | ISBN 978-92-0-103825-8 (paperback : alk. paper) | ISBN 978-92-0-103925-5 (pdf) | ISBN 978-92-0-104025-1 (epub)
Subjects: LCSH: Nuclear reactors — Safety measures — Congresses. | Nuclear facilities — Safety measures — Congresses. | Nuclear reactors — Design and construction. |
Classification: UDC 621.039.58 | STI/PUB/2108

# FOREWORD

The International Conference on Topical Issues in Nuclear Installation Safety: Strengthening Safety of Evolutionary and Innovative Reactor Designs took place in Vienna from 18 to 21 October 2022. Over 300 nuclear safety professionals from 61 Member States and 4 international organizations attended the conference, including representatives of regulatory bodies, design and operating organizations, technical support organizations and research institutions involved in activities relating to the safety of evolutionary and innovative reactor designs.

The conference was tailored to comprehensively address safety concerns relating to evolutionary and innovative reactor designs, aiming to facilitate the exchange of experiences and discussions on potential solutions, to promote the harmonization of safety approaches and to further enhance regulatory frameworks to effectively manage these challenges. Discussions pointed to the importance of applying IAEA safety standards to ensure robust safety demonstration for these types of reactor as well as the need to harmonize and standardize safety approaches and to enhance international collaboration on safety aspects of innovative technologies. The discussions also highlighted challenges regarding the use of software tools for accurate safety assessment of innovative reactor designs. The conference emphasized the importance of integrating insights from both deterministic and probabilistic safety analyses for various safety aspects of evolutionary and innovative reactor designs, particularly for topics such as defence in depth and the classification of structures, systems and components.

This publication provides a summary of the panel discussions and parallel technical sessions, as well as the opening and closing speeches. The full papers from the oral sessions and e-papers as presented at the conference are included as supplementary files available on-line.

The IAEA is grateful to its cooperating partners, the European Commission Joint Research Centre, the European Technical Safety Organisations Network, the OECD Nuclear Energy Agency and the World Nuclear Association. The IAEA also thanks the members of the Scientific Programme Committee, the Secretariat of the Conference and the contributors involved in the preparation of this publication. The IAEA officers responsible for this publication were S. Poghosyan of the Division of Nuclear Installation Safety and T. Jevremovic of the Division of Nuclear Power.

**CONTENTS**

# 1. INTRODUCTION

## 1.1. BACKGROUND

The IAEA International Conference on Topical Issues in Nuclear Installation Safety (TIC) is a recurring event that brings together nuclear safety regulators, plant designers and operators, technical support organizations, and other stakeholders from various Member States, along with international organizations. Since its inception in 1998, the conference has been held in various locations including Vienna, Austria (2001, 2013, 2017), Beijing, China (2004), and Mumbai, India (2008). These international conferences have played a significant role in facilitating the exchange of insights and experiences regarding the latest advancements in the field of nuclear installation safety.

Previous conferences have addressed topics ranging from continuous safety improvement and ensuring safety for existing nuclear installations to the issues related to safety demonstration of advanced water cooled nuclear power plants (NPPs). In recent years, there has been a notable shift in focus among Member States towards evolutionary and innovative reactor designs, particularly small modular reactors (SMRs).

A robust safety demonstration and a well-structured regulatory framework are fundamental prerequisites for the successful deployment and operation of these reactors. Despite the significant strides made over the years in enhancing the overall safety of nuclear installations, the emergence of new reactor designs and fuel cycles has also brought some challenges. Limited experience in the application of the safety approaches for innovative reactors is a significant one. Other challenges, namely, ensuring the proper safety demonstration of innovative safety features in designs, achieving harmonization and standardization of regulatory frameworks to accommodate new technologies, and integrating the principles of safety, security, and safeguards (3S) into the design process have taken centre stage. These challenges remain of utmost importance to regulatory bodies, designers, operating, and technical support organizations across various Member States.

The seventh of the IAEA International Conference on Topical Issues in Nuclear Installation Safety: Strengthening Safety of Evolutionary and Innovative Reactor Designs (TIC2022) was convened in response to emerging trends and needs within the nuclear industry. Held in Vienna from October 18 to 22, 2022, TIC2022 was focused to comprehensively address the issues related to the safety of evolutionary and innovative reactor designs. The conference aimed to promote harmonization of safety approaches in this area and further enhance regulatory frameworks to cope with these challenges. In addition to safety considerations, TIC2022 placed a particular emphasis on the integration of security and safeguards measures into the design of such reactors, with a focus on understanding and addressing the interfaces between safety, security, and safeguards considerations.

This publication presents the main findings of TIC2022, relevant challenges, and proposed recommendations. This publication is organized in two volumes; the first includes the opening addresses, a summary of the panel and conference topic discussions, and the conclusions of the conference. The second volume or supplementary files, available on-line, contain by topic the full papers presented at the conference.

## 1.2. OBJECTIVES AND TOPICS

The objective of TIC2022 was to foster the exchange of information on wide-ranging aspects, capturing the progress and challenges in safety and licensing of evolutionary and innovative reactor designs.

The four topics the conference covered during TIC2022 were the following:

- **Topic 1 - Applying safety approaches and standards for evolutionary and innovative reactor technologies;** This topic focused on the regulatory frameworks required for the licensing of innovative designs with novel technologies. It explored opportunities to strengthen international cooperation in the area of safety and licensing of innovative technologies. In addition, it covered the aspects related to implementation of safety, security, and safeguards (3S) by design in the regulatory frameworks.

- **Topic 2 - Enhancing safety by innovative design features;** The topic covered Member States' experiences with the inherent safety features and passive systems as well as other design characteristics for evolutionary and innovative reactors. It reviewed current challenges and discussed the need for internationally accepted approaches, to address the challenges presented by innovative concepts, such as transportable NPPs.

- **Topic 3 - Supporting integrated decision making through safety/risk analyses;** This topic covered the current trends in the area of safety demonstration of evolutionary and innovative reactor designs and recent developments on Deterministic Safety Analysis (DSA) and Probabilistic Safety Assessment (PSA) for these reactors. It also covered the specific topics of safety analyses for innovative reactors, such as external hazards evaluation, severe accident analysis and multi-unit or multi-module risk analysis.

- **Topic 4 - Accelerating innovations for safety assessment through the advanced simulation and modelling, and experimental programmes;** This topic covered the application of advanced modelling techniques for assessing safety performance of the evolutionary and innovative reactors. It also addressed, specific topics connected with use of artificial intelligence (AI) for safety and use of experimental and computational data and tools to accelerate deployment of innovative reactors.

The summary outcomes of the topical sessions are provided in Sections 4-7 of this report. In addition to the topical sessions, the conference also has foreseen the following plenary and topical panel discussions on key topics relevant to the conference.

- Plenary 1: Harmonization of safety approaches: regulatory and industry perspectives;
- Plenary 2: Challenges, and path forward of the safety demonstrations for evolutionary and innovative reactors;
- Plenary 3: SMRs and microreactors: design challenges and path forward;
- Topical panel: Safety, security and safeguards interfaces and challenges.

The summary outcomes of the discussions during the panels are provided in Section 3.

## 1.3. TIC2022 ORGANIZATIONAL ARRANGEMENTS

TIC2022 was steered by the Conference President Ms Rosa Sardella (ENSI, Switzerland) and the Scientific Programme Committee (SPC) and Conference Secretariat from IAEA. The SPC had eighteen members representing various stakeholders (e.g. regulators, designers, researchers, academia) and different Member States. The complete list of SPC members and the Conference Secretariat can be found in Appendix 1 and Appendix 2.

The conceptual timeline and main organizational milestones of the conference are summarized in Figure 1.

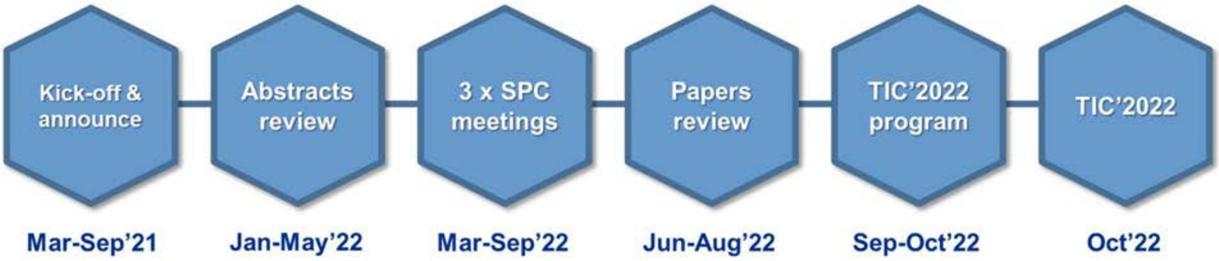


*Figure 1. TIC2022 timeline and organizational milestones*

With the objective to disseminate information about the conference among large number of professionals, the conference promotion began with more than a year before the start and utilized various methods (social media, newsletter, etc.).

The conference abstracts and contributions were thoroughly reviewed by the SPC and discussed during the virtual SPC meetings organized around the abstracts and paper submission's deadlines. As part of their roles and responsibilities, the review of the abstracts and, later, the full papers, by the SPC members was important to ensure the technical quality of the material presented during the conference. The outcome of the SPC review of the abstracts and papers was tailored to proposing for discussion to 1) accept, 2) accept with modification, 3) reject, or 4) reallocate abstract or papers to another topic within the conference. Once all contributions were reviewed and final decision was made about their status, the SPC proceeded with the development of the conference programme (see Appendix 3).

Different from its predecessors, the TIC2022 was implemented in a hybrid mode (in person and virtual) to adjust to the restrictions associated with the COVID-19 pandemic. Therefore, in addition to the in-person and virtual presentations, the plenary and technical sessions were organized showcasing pre-recorded videos of the authors who were not able to join the conference physically. At the end of the pre-recorded presentation, authors addressed questions raised by the audience and those submitted through the IAEA Conference App.

## 1.4. PARTICIPATION AND STATISTICS

More than 300 participants from 61 Member States (see Figure 2) and four (4) International Organizations had the opportunity to share their experience and contribute to the topical discussions.

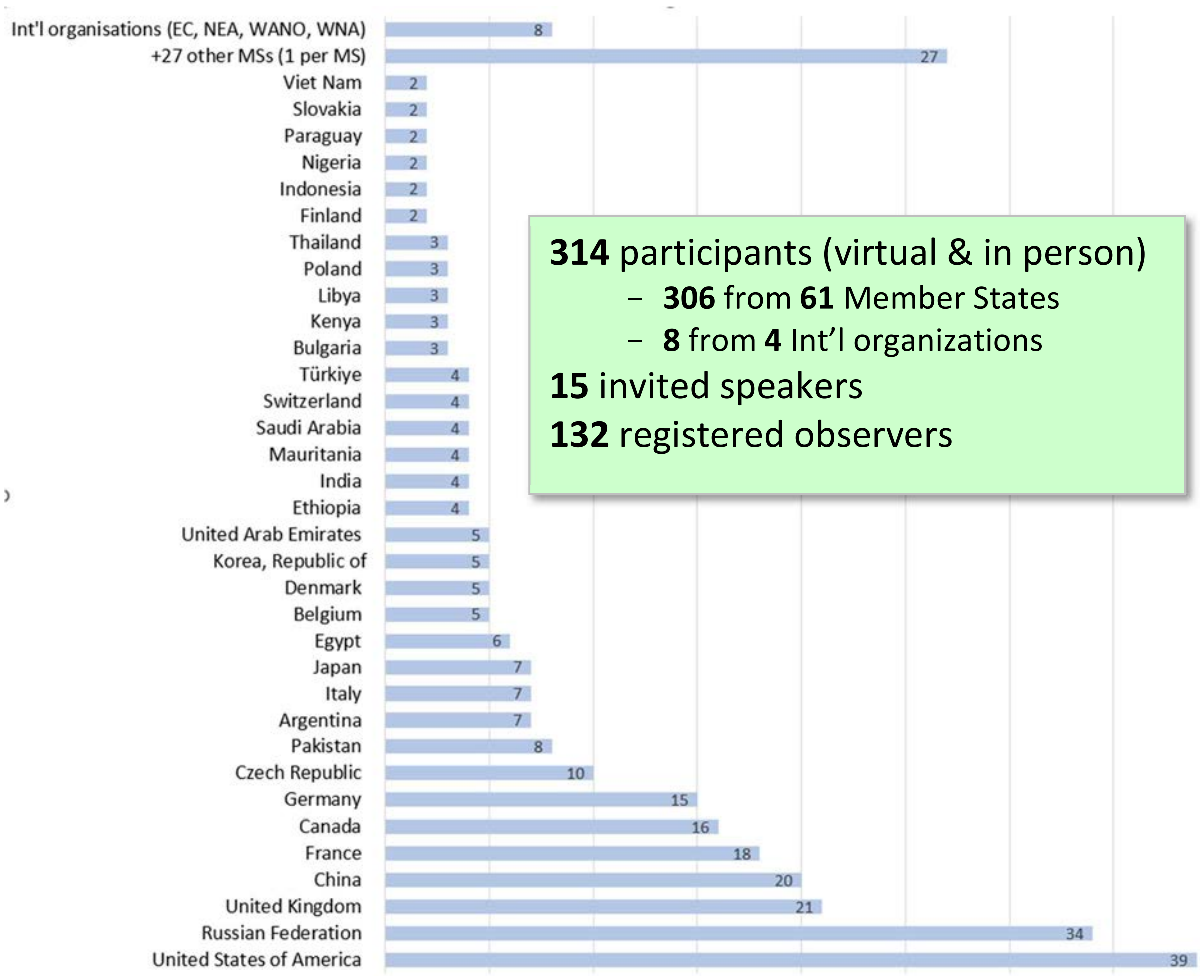


*Figure 2. TIC2022 participation by the Member States and International organizations*

Figure 2 presents explicitly the countries which were represented by two or more participants (34 Member States). 27 other Member States were represented by one participant per country[1] and their participation is reflected as a one separate bar. In addition, the conference was attended by 8 representatives from 4 international organizations, in particular from the European Commission (EC), OECD Nuclear Energy Agency (NEA), World Association of Nuclear Operators (WANO), and World Nuclear Association (WNA). Finally, 15 invited speakers from various Member States participated in the plenary and topical panel discussions. The conference was also extensively attended by IAEA staff, who were participating in the technical discussions, chairing the sessions (see Appendix 3) and providing topical presentations.

The conference received a total of 193 abstracts, out of which 173 abstracts were accepted for presentation in the conference, some rejected, and some requested to merge in a single paper. Eventually after the reviewing and screening process, in total 126 papers were presented orally

[1] The following Member States were represented by one participant per each of the country: Austria, Armenia, Belarus, Benin, Brazil, Comoros, Congo, Cuba, Ghana, Hungary, Islamic Republic of Iran, Israel, Jordan, Mali, Mexico, Morocco, Netherlands, Oman, Philippines, Romania, Rwanda, Singapore, South Africa, Sweden, Uganda, Ukraine and Yemen.

in four parallel sessions representing four Topics of the Conference and 8 papers were displayed as virtual poster presentations (E-session). A good balance was achieved in the paper distribution among the Conference Topics (see Figure 3).

In addition to the papers submitted and accepted for the conference, IAEA and invited speakers provided more than 10 topical presentations summarizing the ongoing activities, trends and challenges in corresponding areas. These topical presentations were usually scheduled before each of the sub-topics and they allowed the session chairs to set up the scene for various subtopics and provided better understanding of the future outlook for that particular area.

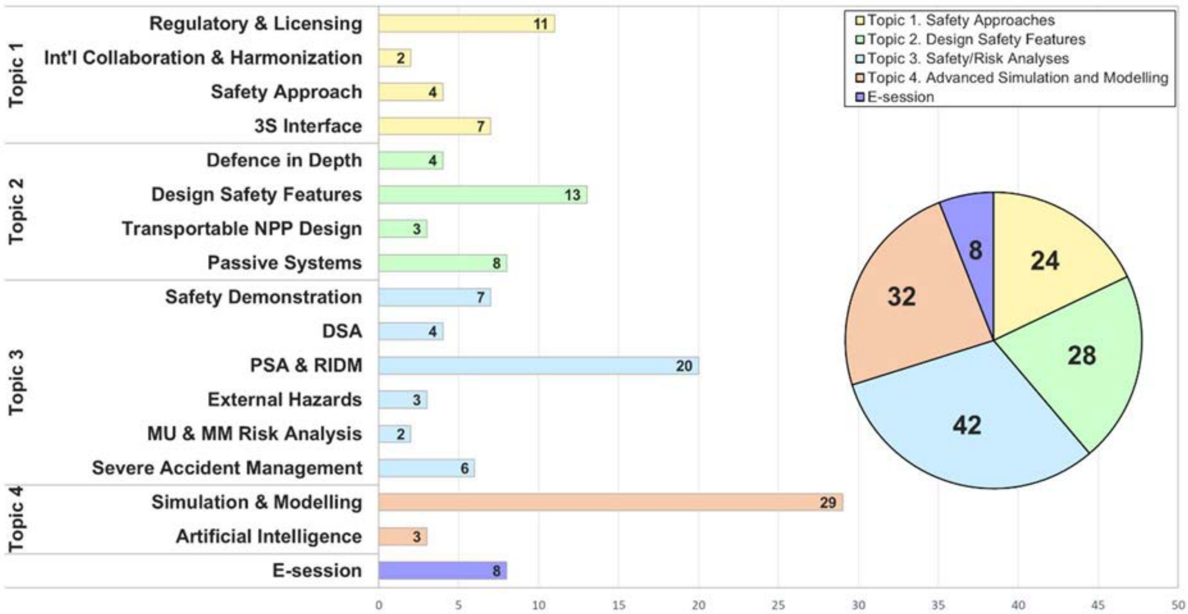


*Figure 3. Distribution of papers among topics and subtopics*

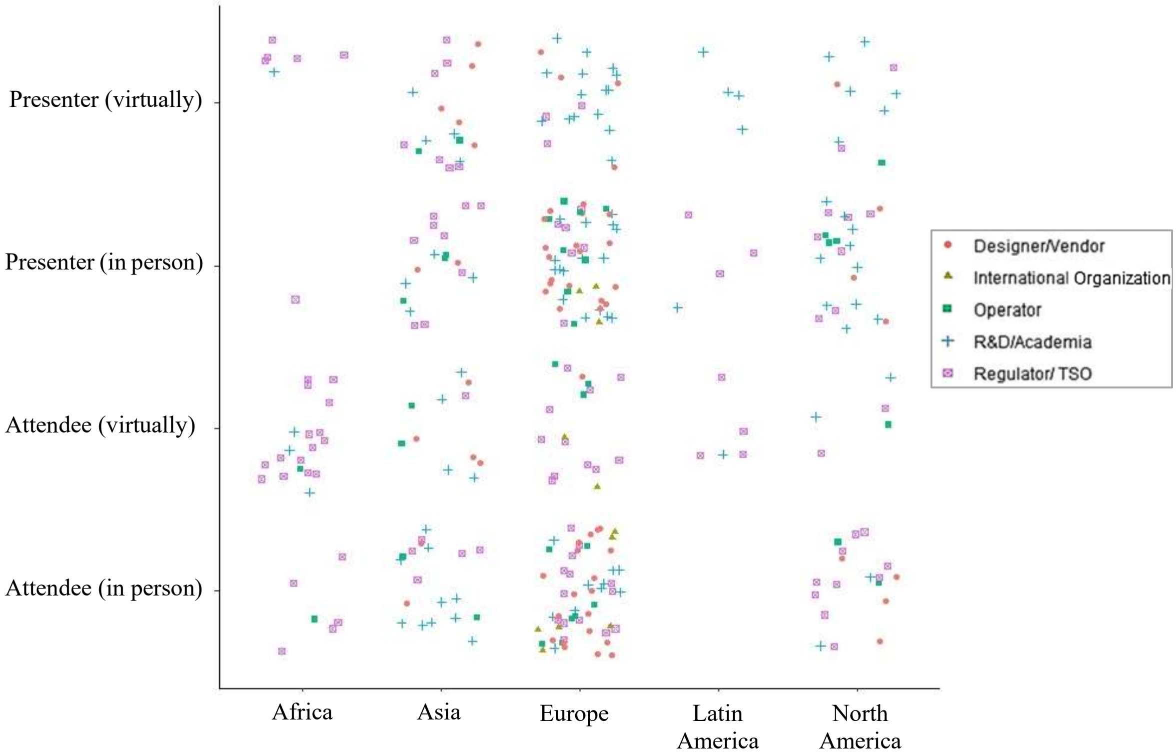


*Figure 4. TIC2022 participation by region, industry type and participation mode*

The balanced distribution of the papers and presenters from various stakeholders and Member States facilitated fruitful discussions during the conference and helped the Secretariat to identify key outcomes and call for actions. The TIC2022 conference attracted a diverse group of professionals and achieved balanced participation among experts representing various stakeholders and Member States (see Figure 4).

# 2. OPENING REMARKS

## 2.1. OPENING REMARKS DELIVERED BY THE INTERNATIONAL ATOMIC ENERGY AGENCY DIRECTOR GENERAL

(As prepared for delivery)

RAFAEL MARIANO GROSSI

Director General of the IAEA

Ladies and gentlemen,

It is a pleasure to welcome you to Vienna for the International Conference on Topical Issues in Nuclear Installation Safety. The theme of the conference is quite clear: strengthening safety of evolutionary and innovative reactor designs.

It's quite simple; our robust safety demonstration is a prerequisite for the successful deployment of innovative reactors. The importance of achieving that is growing by the minute. Today's combined crises of climate change and energy security means we have no time to waste to be part of the solution. I am determined to maximize the assistance and impact IAEA can have in this area. New technology can bring important benefits to our existing reactors and will offer new solutions to a world increasingly interested in nuclear power, but this will only happen if safety and security come first. I am pleased this conference offers you a chance to exchange information and knowledge and to discuss the progress achieved so far. But I am also interested in how in concrete ways we can address the opportunities and the challenges we have before us.
New nuclear technologies are evolving rapidly and emerging from different parts of the globe, more than eighty SMR designs are under development in nineteen countries. Their unique designs offer opportunities for industries and countries for whom larger reactors are unsuitable. So, we are attracting attention from countries with existing nuclear reactors and from those without them. Developing countries especially are looking to the IAEA for guidance, for advice on SMRs, as they look for reliable and affordable low-carbon energy sources to fuel their economies while mitigating air pollution and greenhouse gas emissions. That's why we have developed the agency wide SMR portal to inform, and to exchange information on SMRs. The growing interest makes me even more determined that the IAEA assists in facilitating the timely and safe deployment of this vital technology.

I know many of you agree about the importance of harmonization. Earlier this year, I launched the Nuclear Harmonization and Standardization Initiative, bring together all stakeholders to facilitate safe and secure deployment of SMRs, through standardization of the design and harmonization of regulatory activities. Nuclear power requires the highest standards of safety and security; it is indispensable for public, government and investors. We need to get it right, we need to get there fast, and for that we must be really smart.

With many technologies and designs at the development stage right now, we have a unique window to ensure that safety, security, and safeguards measures are implemented by design, in an integrated manner considering their interfaces. I encourage Member States to request the IAEA to conduct independent peer reviews of safety on their design. But this is a two-way street, your feedback to us is important too. We welcome your voice on the applicability of

IAEA safety standards in the context of developing and advancing technologies. In closing, let me wish you a productive conference, and say that I look forward to hearing about its results.

## 2.2. OPENING REMARKS DELIVERED BY THE DEPUTY DIRECTOR GENERAL OF THE DEPARTMENT OF NUCLEAR SAFETY AND SECURITY

(As prepared for delivery) LYDIE EVRARD

Deputy Director General

Department of Nuclear Safety and Security, IAEA

Dear ladies and gentlemen,

I would like to extend a very warm welcome to all of you to the International Conference on Topical Issues in Nuclear Installation Safety: Strengthening Safety of Evolutionary and Innovative Reactor Designs.

We are currently in a period of evolution in the nuclear industry, and in light of current efforts to combat climate change and to meet the increased global energy demands, many countries are looking to nuclear technologies to reach their goals. The Agency recognizes the important role that evolutionary and innovative reactors, including small modular reactors (SMRs), will play. Throughout this week, the IAEA will facilitate much needed discussions and information exchange on the safety of evolutionary and innovative reactors, a key area of interest for the IAEA and our Member States.

With 80 SMR designs under development in 19 countries, these new technologies are gaining increased interest among our Member States, including countries embarking on new nuclear power programmes. Nuclear safety and security must be at the core of these developments, and I know that all our stakeholders share this vision.

The IAEA is well aware of the extensive work being carried out worldwide in preparation for the licensing of these advanced technologies, and of the challenges being faced, and we are committed to support our Member States to enable the safe and secure deployment of advanced reactors.

I would also like to highlight the IAEA Nuclear Harmonization and Standardization Initiative (NHSI), launched by our Director General in March this year. Under this initiative, we are working with governments, regulators, technology holders, operators, and other international organizations to facilitate international cooperation on advanced reactors.

The key objective of NHSI is to avoid unnecessary duplication of regulatory and industry efforts and minimizing the need to modify the designs to meet different requirements and standards in different countries while still maintaining high levels of safety. During the conference, we will discuss harmonization opportunities and international collaboration. Your insightful feedback and the outcomes of this conference will help us to move forward with this important initiative.

Ladies and gentlemen,

Evolutionary and innovative reactor designers claim safety advantages over existing designs. Indeed, this is a key expectation from the advanced technologies. However, these claims must be backed by robust safety demonstrations. These safety demonstrations can be challenging for reactor designs which have not yet reached high levels of maturity.

Aware of these challenges, and with the IAEA safety standards as the cornerstone of global nuclear safety, the Agency has completed a review of the applicability of the safety standards to non-water-cooled reactors and SMRs. This work concluded that many aspects of the IAEA safety standards are applicable to these reactors. However, it also identified gaps and areas where work will be needed to address specific aspects related to innovative technologies. The outcome of this work is compiled in a Safety Report and the pre-print version is already available to the public.

As a continuation of this effort, the IAEA has initiated the development of a Safety Guide on "Safety demonstration of innovative technology in power reactor designs", and during this conference we will be seeking inputs for this important work, to help us better understand the challenges and gather recommendations on this topic.

In addition, the Agency has also put in place an intensive programme of work to ensure that future reviews of the IAEA safety standards will consider the new technologies. In the meantime, we are developing technology specific publications to provide further information on the safety of these designs.

Ladies and gentlemen,

When talking about nuclear safety, we cannot neglect the interfaces with nuclear security and nuclear safeguards. It is therefore paramount that safety, security, and safeguards, the 3S, be taken into account from the beginning of the design of new reactors. Many SMRs and other innovative reactors are in early design stages, and this provides opportunities to comprehensively integrate all three elements, and effectively optimize the designs.

We should not miss this unique opportunity, and I would also like to stress that the active involvement of all relevant parties is essential for the consistent approach to 3S.

Ladies and gentlemen, colleagues,

The Agency's commitment to support the safe and secure deployment of advanced reactors is unwavering. However, we cannot succeed without the clear commitment and support from governments, regulatory bodies and industry.

I am pleased to see a wide spectrum of stakeholders represented in this conference, particularly because I believe that the active involvement of all stakeholders is an absolute prerequisite for effective and successful strengthening of the safety of evolutionary and innovative reactors.

Ladies and gentlemen,

To conclude:
I would like to warmly thank Ms Rosa Sardella for being the President of this conference this week, Rosa Sardella from Switzerland, thank you very much Rosa for running this conference this week. I would like to thank all those committed to the preparations of this conference, in particular from the Department of Nuclear Safety and Security and the Department of Nuclear Energy, and in particular the two scientific secretaries.

I would like to wish you all a successful week and look forward to the key take aways from the conference deliberations to progress towards harmonized approaches and practices in the areas of design safety, safety assessment and licensing of evolutionary and innovative reactor designs.

I will now hand over to the Scientific Secretaries of the Conference.

Thank you.

## 2.3. OPENING REMARKS DELIVERED BY THE DEPUTY DIRECTOR GENERAL OF THE DEPARTMENT OF NUCLEAR ENERGY

(As prepared for delivery)

MIKHAIL CHUDAKOV

Deputy Director General

Department of Nuclear Energy, IAEA

Dear Lydie, colleagues, ladies and gentlemen,

On behalf of the IAEA Department of Nuclear Energy, I also extend my warm welcome to all of you to this important event. It’s great to see everyone here in person, and it’s a pleasure to share a few words with you at the start of four days of intensive discussions.

Your talks this week are timely.

Faced with the need to address both climate change and the global energy crisis, interest in nuclear power is rising worldwide. Countries from Africa and the America’s to the Middle East and Asia are recommitting to nuclear power. And around 30 nations are working with the IAEA as they consider or embark on nuclear power for the first time, with newcomers Bangladesh and Türkiye already building their first reactors.

The Agency’s annual projections for the future of nuclear generating capacity, released just last month, increased for the second year in a row, reflecting a shift in the global debate over energy and the environment. Nuclear generating capacity in our high case scenario is projected to more than double by 2050 to 873 gigawatts.

The global shift in attitudes about nuclear power was on display last month at the IAEA’s 66th General Conference here in Vienna. A record number of countries officially recognized its key role in addressing current global challenges and achieving goals such as climate change mitigation, energy security and sustainable development.

Many countries are closely watching the exciting developments under way in the nuclear sector, especially SMR and innovative technologies on the horizon. As you have heard, there are more than 80 SMR designs under development or construction worldwide—and technical details on all of these designs can be found in the latest update of our SMR booklet, published last month.

Ladies and gentlemen,

The safety of these new designs is of paramount importance. And, as Lydie described in her opening remarks, the IAEA plays an important role in this area. This includes initiatives related to our safety standards, which are a key international reference and support Member States in IAEA safety peer reviews.

Innovative reactor technology, and the promise it offers, has long been a key part of the Department of Nuclear Energy's work. Our International Project on Innovative Nuclear Reactors and Fuel Cycles, or INPRO, assesses the sustainability of nuclear energy systems, including innovative reactors. Among other things, INPRO activities consider how to measure a nuclear energy system's proliferation resistance, its economic merits, and to demonstrate progress on safety by design.

For innovative designs, there is a unique time window available now to implement safety, security and safeguards measures by design in an integrated manner considering their interfaces. This is vital opportunity to ensure that all areas are served in the best possible way.

In particular, I would emphasize the importance of harmonizing safety approaches and practices in the area of design safety, safety assessment and licencing of evolutionary and innovative reactors.

To support the effective deployment of safe and secure advanced reactors, including SMRs, the Agency has taken some important steps recently. The new Nuclear Harmonization and Standardization Initiative, for example, is working with Member States to achieve enhanced harmonization of regulatory activities and the standardization of industrial approaches. And the IAEA Platform on SMRs and their Applications, launched one year ago, is providing Member States with streamlined access to all the Agency's services and support on SMRs, from technology development and deployment to nuclear safety, security and safeguards.

International cooperation and the exchange of information among stakeholders is vital to support design innovations and safety assessments. The Agency also offers useful tools in this area, including for advanced simulation and modelling and cutting-edge experimental programmes.

Our nuclear power plant basic principle simulators for education and training, available to all Member States, simulates the behaviour of the existing types of reactor. And we are soon to release our new simulators on severe accidents in water cooled reactors, and simulators on high temperature gas cooled reactors and sodium cooled fast reactors.

Ladies and gentlemen,

As I said at the outset, the global spotlight is now shining on the potential for nuclear power to address some of the world's major challenges. Indeed, this conference is just the latest major international event where nuclear power, and its future are coming into sharp focus.

At the UN Climate Change Conference next month in Egypt, the Agency will for the first time ever oversee a pavilion dedicated to showcasing the benefits of nuclear science and technology for climate change mitigation and adaptation. For two weeks, the #Atoms4Climate Pavilion will feature events organized by the IAEA and its many partners.

But first, next week, in Washington DC, we will hold the International Ministerial Conference on Nuclear Power in the 21st century. Ministers, senior officials, policy makers and experts from around the world will discuss a number of vital issues. One panel discussion be dedicated to effective regulatory oversight for the future of nuclear power.

I trust your deliberations here this week will help inform these discussions in Washington DC. But beyond that, I am confident that this conference will achieve important outcomes. These will help focus the Agency’s work in several areas and advance efforts on the safety and security of evolutionary and innovative nuclear reactors.

I wish you all a great conference and the best of luck.

Thank you.

# 3. CLOSING REMARKS

## 3.1 CLOSING REMARKS DELIVERED BY THE HEAD OF THE SAFETY ASSESSMENT SECTION IN THE DIVISION OF NUCLEAR INSTALLATION SAFETY

(As prepared for delivery)

ANA GOMEZ COBO

Section Head of the Safety Assessment Section, Division of Nuclear Installation Safety

Department of Nuclear Safety and Security, IAEA

Ladies and gentlemen,

As we come to the closure of this important conference that outlined the highlights on the progress and outlook of the safety of evolutionary and innovative reactor designs, I would like to take this opportunity to thank you all for your contributions, engagement, and fruitful discussions on a field of vital interest for the IAEA.

The activities pertaining to the safety and security of all nuclear reactors are a priority for the Agency, and your feedback to us is important, and will be taken into consideration for our future work on the safety of evolutionary and innovative reactors designs.

Convening over 60 Member States this week has empowered important discussions on how the future of innovative reactors should look like.

Particularly, our focus is to ensure that the important innovations introduced by innovative reactors are fully considered and consistent with current safety, security, and regulatory approaches.

We, at the IAEA, have established different channels to facilitate and sustain cooperation amongst all stakeholders to enable the safe and secure deployment of SMRs and other advanced reactors.

This week we heard that the IAEA Nuclear Harmonization and Standardization Initiative (NHSI) is a complex and ambitious undertaking, nevertheless, a necessary mechanism to work on standardization of design and harmonization of regulatory activities.

NHSI is up and running; working group meetings are taking place and keeping an open mind will be essential to make substantive progress; to avoid unnecessary duplication of regulatory and industry efforts and to minimize the need to modify the designs to meet different requirements and standards in different countries while still maintaining high levels of safety.

Ladies and gentlemen,

We, at the IAEA, have also put in place an intensive programme of work to ensure that future reviews of the IAEA safety standards address the identified gaps and areas of further work resulted from the Safety Report on the applicability of safety standards to non-water-cooled reactors and SMRs, available as a preprint on our website.

We are also developing publications to provide examples of practical application of safety standards and security approaches to SMRs and innovative technologies and help Member States to overcome limitations in regulatory and operating experience in relation to these designs.

Your inputs this week were important for the development of a key Safety Guide on "Safety demonstration of innovative technology in power reactor designs" and helped us better understand the challenges and recommendations of developing guidance general enough to cover different design and technologies, as well as preferred approaches to gather experiences on this topic.

Ladies and gentlemen,

This week, we reached to a strong consensus that robust safety demonstrations are a paramount requisite for the deployment of first of a kind designs.

A clear commitment and collaboration from governments, regulatory bodies, and industry, sharing experience, and results from experimental and R&D in the context of developing and advancing technology in a safe and secure way is a prerequisite to pave the way forward.

Another conclusion from this week deliberations is that nuclear safety, security, and safeguards, the 3S, shall be taken into account from the beginning of the design of new reactors. We are glad to confirm that developers and all relevant parties are aware of this unique opportunity to implement safety, security and safeguards measures by design in an integrated manner considering their interfaces. and the regulatory framework needs to have a 3S mindset.

Ladies and gentlemen,

I hope my brief remarks have provided you with an overview of the extensive amount of work we are undertaking to provide Member States with the most efficient support for the safety of evolutionary and innovative reactor designs.

The outcomes of this conference will be published as conference proceedings. The 8th IAEA International Conference on Topical Issues on Nuclear Installations Safety will be organized in 2026.

Thank you.

# 4. SUMMARY OF THE PANEL DISCUSSIONS

## 4.1. PLENARY 1: TOWARDS HARMONIZATION OF SAFETY APPROACHES: REGULATORY AND INDUSTRY PERSPECTIVES

The first plenary, chaired by Ms. K. Alm-Lytz, Section Head of the Regulatory Activities Section at the IAEA, focused on the challenges and path forward in terms of harmonization of regulatory activities and the standardization of industrial approaches. The IAEA provided an initial overview of the benefits of harmonization, standardization, collaboration, and minimizing repetition among regulatory reviews and design changes for advanced reactors in different countries, while maintaining national responsibility by the competent authority. Following which, in their opening remarks, each of the five panellists provided an overview of strategies for an efficient and safe harmonization process and deployment of advanced reactors.

The plenary was composed of the following panellists:

- R. Velshi, Canada/CNSC;
- S. Cadet-Mercier, France/ASN;
- M. Uesaka, Japan/JAEC;
- J. Ball, USA/GE-Hitachi;
- S. Bilbao y León, WNA.

The discussion focused on the challenges and opportunities for harmonization of regulatory approaches to SMRs. The panel members emphasized that harmonization does not include relinquishing national independent regulatory decision making, it does not involve all regulators adhering to a single set of requirements, and it does not mean that a reactor licensed in a country will automatically be licensed in another one. Discussing the harmonization efforts, the panellist highlighted that during the harmonization efforts it needs to be ensured that countries preserve their sovereignty. At the same time, regulators were encouraged to be open-minded and to advance their regulatory frameworks to address new technologies.

The panel members emphasised the fact that regulatory independence does not mean isolation, as the regulator needs to have access to the entire spectrum of available information for proper decision making. Elaborating on this, the panel members believe that finding consistency with requirements would not be possible in all aspects, but it will help achieving standardization of reactor designs throughout the lifetime of the new technologies. In terms of regulatory initiatives, the panel suggested that bilateral and trilateral efforts could inform multilateral efforts with lessons learned. However, they cautioned that harmonization is not the ultimate objective, but rather convergence of requirements.

The upside of achieving the final goal despite the challenges were largely elaborated by the panel members. For instance, panellists considered streamlining regulatory review processes and standardization of designs not as a choice, but as a necessity. This was highlighted in the context of the urgency to increase nuclear energy reliance for decarbonization and energy security when combating climate change. In the meantime, it was noted that the industry standardization also has its limits, which needs to be considered.

The panel agreed that streamlining and harmonizing will push the SMR business model, global market and supply chain, to be fully realized. It was emphasized that the nuclear society is currently at a unique point in time in which similar technologies are being deployed around the world within similar timeframes. This context lends itself to drive the collaboration among regulatory bodies, and it needs to be optimized by facilitating the ability of one regulator to adopt or infuse in their review the outcomes from another regulator. The panel participants concluded that the challenges with innovative technologies (limited operating experience, lack of expertise and experiences in regulatory bodies) and the aggressive timelines add pressure to regulators to streamline review processes and become more efficient. It was concluded that to prevent the duplication of efforts and achieving the goal of global deployment of safe and secure SMRs, different countries and regulatory authorities need to collaborate.

## 4.2. PLENARY 2: SAFETY DEMONSTRATIONS FOR EVOLUTIONARY AND INNOVATIVE REACTORS: CHALLENGES AND PATH FORWARD

The second plenary, chaired by Ms Ana Gomez Cobo, Section Head of the Safety Assessment Section at the IAEA, discussed the challenges in safety demonstration focusing on innovative and first of a kind reactors. Providing a credible safety demonstration could be more complex for novel technologies than for the current operating fleet. In particular, there are no written standards to underpin such demonstrations, there is limited experience in this area, and a need for further guidance as identified in IAEA Safety Reports Series No. 123, 2023[2]. Currently, the IAEA is actively developing publications on safety demonstrations for innovative reactors to address the above-mentioned challenges (e.g. new IAEA Specific Safety Guide DS537). Being a key topic for the Conference, the second plenary discussions circled around the necessity of having a robust safety demonstration for successful deployment of an innovative reactors.

The plenary was composed of the following panellists:

- C. Viktorsson, UAE/FANR;
- R. Taylor, USA/USNRC;
- H. Perry, UK/Rolls-Royce SMR;
- U. Stoll, Germany/ETSON.

Innovative technologies in reactor designs bring specific challenges in terms of safety demonstration and licensing. During the plenary, speakers emphasized that the designers need to systematically identify all potential risk contributors for a given innovative reactor design, basically responding to the question “what can go wrong?”. The panel highlighted that the deep understanding of the specific phenomenology for given innovative technology is of key importance for the designers in the context of safety demonstration. At the same time acquiring this understanding is one of the main challenges connected with innovative reactors, i.e. first-of-a-kind designs for which there may be limited knowledge and experience gaps.

The panellists pointed out that regulators need to be open minded and need to embrace potential challenges and unknowns connected with first of a kind technology (e.g. inherent safety features, and extensive use of passive safety features). Along with this, panellist believe that a

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Applicability of IAEA Safety Standards to Non-Water Cooled Reactors and Small Modular Reactors, Safety Reports Series No. 123, IAEA, Vienna (2023).

predictable environment is important for designers as they need to know what to do and demonstrate.

Speakers underlined the importance for a regulatory body to receive high quality technical information, as part of the licensee application process. Vendors need to be clear about the design and their safety related decision making process. Panellists believe that to streamline the safety demonstration and licensing process, it is necessary to engage stakeholders from the early stages of design development in order to ensure clarity of expectations from the beginning.

Finally, panellists concluded with a clear message aimed to vendors and design organizations: new technologies have the potential to have substantial safety margins, but it is not enough to state that a design is safe, this has to be demonstrated in a robust and comprehensive safety case.

### 4.3. PLENARY 3: SMALL MODULAR REACTORS NAND MICROREACTORS: DESIGN CHALLENGES AND PATH FORWARD

The third plenary served as a platform for discussion on the specific design related challenges that designers face in the context of SMRs and microreactors, and the vision regarding the path forward. The plenary was moderated by Ms Aline Des Cloizeaux, Director of the Division of Nuclear Power in the Department of Nuclear Energy of the IAEA. The plenary was composed of the following panellists:

- M. Nichol, USA/NEI;
- F. Dermarkar, Canada/AECL;
- S. Pedre, Argentina/CAREM;
- D. Francis, France/EDF.

The panel members emphasized that safety and economics are complementary when it comes to innovative reactors. They noted that materials sciences are just as important as thermohydraulic and physics considerations, and that materials need to be tested under different conditions to better understand the behaviour of reactors during operation. The panel also highlighted the importance of a robust and resilient supply chain for the successful deployment of evolutionary and innovative reactors. This includes developing expertise in advanced manufacturing and utilizing measures to prevent bottlenecks and provide alternatives in case of manufacturing chain errors.

The panel members recognized that there may be differences in professional opinions among and within different stakeholders involved in the deployment of new nuclear technologies, such as designers, operators, and regulators. By establishing clear processes and communication channels, stakeholders can work together more effectively to identify and address any differences in opinion or potential issues that may arise during the deployment of new technologies. The panel emphasized the importance of collaboration and communication between stakeholders to ensure the successful deployment of new nuclear technologies. By preparing for and addressing potential differences in professional opinion, stakeholders can work together to overcome any challenges and ensure that the deployment process is as smooth and efficient as possible.

When considering non-electrical applications of nuclear technology, the panel emphasized the need to learn from previous experiences and licensing processes. They noted that if a reactor is intended for a non-electric application, the new hazards need to be taken into consideration, and vice versa. The safety impact of a nuclear reactor on a non-electric facility needs to be also carefully evaluated.

Overall, the panel highlighted the importance of considering a wide range of factors, including safety, economics, materials sciences, and supply chain resilience, when deploying advanced reactors. The panel emphasized the importance of a collaborative and information-rich relationship between regulators and industry, as well as careful consideration of risks and impacts when implementing nuclear technology.

### 4.4. TOPICAL PANEL: SAFETY, SECURITY AND SAFEGUARDS (3S) INTERFACES AND CHALLENGES

During the panel discussion, speakers presented on the perspectives and approaches for considerations on 3S for evolutionary and innovative reactors and interfaces between safety, security and safeguards. The panel was moderated by Shahen Poghosyan, Scientific Secretary of TIC2022 from IAEAs Safety Assessment Section.

The panel was composed of the following panellists:

- C. Viktorsson, UAE/FANR;
- R. Jammal, Canada/CNSC;
- A. lyengar, USA/DOE;
- H. Looney, IAEA, NSNS;
- J. Whitlock, IAEA, SGCP.

The main message of the panel was that 3S measures need to be incorporated as early as possible in the design stage and while doing that the 3S interfaces need to be systematically considered. Also, it was mentioned that the potential synergies between safety, security and safeguards need to be exploited where possible during the design process.

Specific attention was paid to the need to reflect 3S requirements in regulatory frameworks. While there is experience in regulatory bodies to have 3S in their regulatory framework, the panel considered that these examples could be formulated as good practices so other competent authorities could absorb the experiences. The panel considered that for successful integration of 3S in the design, one of the most effective ways is to not work in silos, but build the 3S culture within an organization.

Speakers highlighted that for new technologies, there are potentially more synergies between 3S than conflict areas. The international nuclear community increasingly recognizes the benefits of creating synergies between safety, security, and safeguards already by design of nuclear installations. Given the interest among regulators and SMR designers, the discussions underscored the value of the IAEA demonstrating leadership by example in the area of 3S. Moreover, the panellists specifically highlighted the need to consider 3S interfaces in the design review services offered by IAEA and discussed potential application of risk informed approaches not only for safety, but also for security and safeguards.

Discussing about the challenges on practical implementation of 3S concept, the panellists mentioned that educational programmes mostly focus on nuclear engineering and specific safety aspects. However, the security and safeguards related aspects are not properly covered in professional curriculums. Moreover, it was noted that the design organization will benefit from having security and safeguards experts in their staff to create a dialogue as early as possible during the design stage.

# 5. TOPIC 1 - APPLYING SAFETY APPROACHES AND STANDARDS FOR EVOLUTIONARY AND INNOVATIVE REACTOR TECHNOLOGIES

## 5.1. REGULATORY AND LICENSING APPROACHES

With the increased interest in NPPs to help combat climate change, numerous evolutionary and innovative reactor technologies are being developed. These designs impose specific challenges to the existing regulatory and licensing approaches both for new regulators (embarking countries) but also for well-developed regulatory frameworks (i.e. countries with well-established nuclear programmes).

Most regulatory frameworks were designed around large, water cooled reactors (WCRs) and are now being revised to address the evolutionary and innovative designs being considered today. Reviewing and licensing these new designs can be a lengthy and costly process. It is therefore important to consider modernizing the regulatory framework to better address the needs of regulating and licensing reactors incorporating substantial innovative safety features.

Regulators and international organizations are evaluating their regulatory programmes and guidance to determine the applicability of their requirements and guidance and what gaps may exist. The IAEA, for example, has performed a gap analysis of its safety standards and has developed plans to update some of these safety standards over the next few years (IAEA Safety Reports Series No. 123, 2023)[3]. In addition, multiple Member States' regulators are in the process of updating their regulations and guidance. It's not just the new designs that have to be taken into consideration, but also the manufacturing and commissioning aspects of these new designs. Many of these new designs will be SMRs with much of the manufacturing being performed in a factory. In some cases, manufacturing may be performed outside of the country where the facility will be located. Because of the extensive assembly in the factory, some commissioning and testing activities on safety related components will also be performed in the factory. Regulators will need to factor this into their programmes and potentially coordinate with the regulator in the country where the manufacturing is being performed.

Staged licensing approaches (e.g. pre-licensing) can help obtain early regulatory feedback, allowing the identification of safety issues and improvements in the conceptual or generic design or the associated safety demonstration, possibly requiring experimental facilities, in a timely and efficient manner. This approach facilitates identifying and resolving potential safety issues before a reactor is built. A staged regulatory process with meaningful regulatory feedback and milestones can be very beneficial for advanced reactor designers, particularly in the case of demonstration reactors where there may be less regulatory precedent to follow. Additionally, having a stable and clear path to regulatory approval can provide private sector investors or government departments with greater confidence in the project milestones. This, in turn, can

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Applicability of IAEA Safety Standards to Non-Water Cooled Reactors and Small Modular Reactors, Safety Reports Series No. 123, IAEA, Vienna (2023).

help accelerate the development of evolutionary and innovative reactor designs and bring them to market more quickly.

Many of the evolutionary and innovative reactor designs utilize first-of-a-kind technologies, whether it be in the reactor technology itself or in the safety systems. As a result, most regulators do not have practical experience in evaluating these technologies. Some reactor designs may have multiple reactor modules within the same building and could share common safety systems. The designs may also allow for additional reactor modules to be added in the future, either in the same building or at the same site. Most new reactor designs are SMRs and utilize passive safety features and may not need safety related power sources for operation or response to events. With these smaller reactors, licence applicants will be requesting to be allowed to use fewer reactor operators, smaller emergency planning zones (EPZs), and reduced security forces. As regulators prepare for these new and innovative reactor designs, they need to evaluate their regulatory framework and make the necessary adjustments to their regulations and guidance. Several presenters at the conference discussed their goal-oriented approach to regulation and how it provides flexibility to the licence applicants in meeting the regulations and demonstrating safety. Their goal-oriented approach results in a graded approach commensurate with risk of the proposed design.

A topic of significant interest was how a regulator prepares for licensing of innovative reactor designs. This process can be resource intensive, and it was suggested that regulators develop a plan with clear objectives and identify the necessary funding. This applied to both emerging and experienced regulators. The plan needs to address the timeline for the project, the staffing needed to complete the plan, the objectives to be achieved, the funding necessary to complete the plan, and a clear mission statement. One presenter noted that they had identified project pillars: regulatory predictability, policy and shared responsibilities, capacity and capability, and international collaboration. Examples of how to develop a project scope for each of these pillars were presented. It was noted in the discussion that to complete the plan that it may take an organization-wide approach, an organizational shift in completing the work, a holistic approach to readiness, and dedicated staffing.

There was considerable discussion on how a pre-licensing process can be beneficial in identifying possible issues at a very early stage. Several presenters discussed their Member State’s pre-licensing process and how both the applicant and regulator can benefit from early interactions. The approaches varied among the Member States, but the resulting benefits were comparable. From the applicants’ perspective, they can gain feedback on both their design and application content. For example, applicants may choose to make modifications to the design based on discussions and feedback from evaluations performed by the regulator. Proposed methodologies, such as for fuel qualification, can be provided and approved in advance. Similarly, the regulator and applicant can gain agreement on research and development plans, as well as approaches to validation of computer codes. The applicants can gain a better understanding of the requirements and expectations for licence application. From the regulators’ perspective, they can gain considerable knowledge of the proposed design and can prepare for the future licence application review through staff capability development and reviews of regulatory guidance. Depending on the depth of the pre-application process review, a regulator can provide confidence to the applicant that the design can satisfy the regulatory requirements. Regulators can also ensure that there is a focus on the safety, security and safeguards aspects of the design which can lead to development of that culture in the applicant. Early interactions regarding the implementation of safeguards in reactor design is found to be very efficient, and particularly helpful for reactor designers from the nuclear weapon states parties to the NPT (especially if there are plans for the reactor deployment in non-nuclear weapon states parties to the NPT).

When confronted with a challenge, innovation and resilience by regulators can lead to more effective and efficient programmes. When preparing for the licensing of evolutionary and innovative reactor technologies regulators can identify new ways of performing the work. Regulators are considering international collaboration on new reactor reviews as a way to be more effective and efficient and promote harmonization. Numerous efforts are underway in this area.

## 5.2. INTERNATIONAL COLLABORATION AND HARMONIZATION

The topic of international collaboration and harmonization was discussed throughout the conference, particularly, during the specific panel discussion (see 4.1). Although international collaboration and harmonization of regulatory approaches have been attempted in the past with varying levels of success, there is significant renewed interest in achieving this challenging goal. The most prominent effort in this area is the IAEA's Nuclear Harmonization and Standardization Initiative (NHSI). The NHSI has two tracks focusing on how regulators can work effectively together and how the industry can better standardize. Other international organizations are addressing different aspects of harmonization, and some Member States are undertaking bilateral and multilateral collaboration efforts. Effective collaboration is needed between governments, international organizations, regulators, and the industry, all working together with the shared objective of streamlining licensing and regulatory approaches internationally.

As was learned in prior attempts, there are numerous challenges to overcome. Harmonization among regulators will not be easy and it will take time. However, in addressing these challenges, open-mindedness is essential in making progress. Lessons will be learned along the way and sharing these lessons in a timely manner among Member States is key to success.

Collaboration between regulators in two Member States can lead to efficiencies for both regulators and for reactor vendors and licence applicants. In establishing this collaboration, formal agreements among the regulators helps to facilitate the cooperation. This can be accomplished through a memorandum of understanding or other arrangements. These agreements can address how the regulators will communicate, share information, and select projects to work on. It is also important for each regulator to understand the differences in the collaborating regulators' programmes and requirements early in the process. This can lead to more efficient interactions with the reactor vendors and licence applicants and possibly to acceptable designs and safety approaches in each Member State. For the most effective collaboration, the collaborating regulators may consider selecting licensing projects that are at similar phases. Over time, the regulators need to perform a periodic evaluation of their processes and make improvements where necessary. These evaluations and improvements are essential for the success of the collaboration. Multilateral collaboration will benefit from the lessons learned from previous bilateral collaborations.

There are many different new reactor designs being developed and some are currently being reviewed by regulators. Whether these new designs are reviewed by a single regulator or through a collaborative effort, sharing the lessons learned from reviews of SMRs and other innovative reactor designs with other regulators will help to achieve the goal of harmonization and standardization.

One example of bilateral cooperation that was discussed is the US Nuclear Regulatory Commission (NRC) and the Canadian Nuclear Safety Commission (CNSC) cooperation on advanced reactor technologies. A Memorandum of Cooperation (MOC) was signed in 2019 with a goal to collaborate on advanced reactor technologies and SMR reviews and to share experience. The activities under the MOC are overseen by a subcommittee and the work is performed by working groups following documented work plans. So far, several joint reports have been issued on topics provided by reactor vendors in preapplication, a comparison of review approaches, and one on TRISO fuel qualification. Periodically, reviews have been performed to improve the process of how regulatory staff work together and how they communicate with external stakeholders. The collaborative reviews performed under the MOC demonstrate that the NRC and CNSC can successfully cooperate on technical topics and enhance regulatory reviews.

Another presenter provided an update on the regulatory track of the IAEA’s NHSI. To promote the effective global deployment of safe and secure advanced nuclear reactors, the IAEA started the NHSI in June 2022. It consists of two tracks: a regulatory track to address harmonization of regulatory approaches, and an industry track to address standardization of industrial approaches. Working groups have been established and overall scope and timelines for the work have been developed. The working groups began their activities later in 2022 and will work through 2023 with a goal of publishing their findings in 2024. The regulatory track consists of three working groups. Working group 1 is focused on identifying the information that would be most beneficial to share between regulators, potential obstacles, and potential solutions. Working group 2 is focused on the development of a process and criteria for international pre-licensing regulatory review of generic designs. Working group 3 is focused on how to leverage the reviews of other regulators and how regulators can work together during ongoing regulatory reviews. During the initiative, the working groups from both tracks will periodically review the other’s draft products and meet to discuss feedback.

## 5.3. SAFETY APPROACHES

The concept of defence in depth (DiD) continues to be a fundamental pillar of nuclear safety. As new reactor designs are introduced, incorporating novel features such as different coolants and fuels, it is necessary to ensure that implementation of the DiD concept is adequate taking into account these innovations. This will require careful consideration and evaluation of these new features, to ensure that they do not compromise the overall safety of the reactor.

New reactors are being designed which make more extensive use of inherent and passive safety features, in areas such as advanced fuels, reduced reliance on electrical power, and reduced requirements for operator intervention. This approach is aimed at enhancing the overall safety of the reactor, making it more resilient to accidents and reducing the risk of human error. Thus, for instance, the use of advanced fuels reduces the likelihood of fuel failures and facilitates the control of accidents. The implementation of design measures to mitigate severe accidents and the application of the practical elimination concept in design makes very unlikely or excludes significant radioactive releases thereby reducing the scope of severe accident management measures and EPZs and arrangements. For instance, during the conference it was discussed that the application of the practical elimination concept and the reduction of the risk of accidents may enable the siting of SMRs in populated areas depending on a range of factors. These factors include the effectiveness of the design and safety measures implemented in the plants, as well as the quality of the emergency response and mitigation plans in place. Public acceptance will also be a critical factor in determining the viability of SMR projects in populated areas.

## 5.4. SAFETY, SECURITY AND SAFEGUARDS (3S) INTERFACES

The presentations during the panel discussion acknowledged the potential challenges and opportunities related to the consideration of the safety, security, and safeguards and their interfaces in design (see 4.4).

During the technical sessions, it was concluded that regulatory frameworks need to incorporate the 3S mindset. Several presentations noted how regulators adopt a 3S approach in their regulatory framework and have requirements for safety, security, and safeguards to be considered during the design, construction, operation, and decommissioning of nuclear facilities. However, it was also mentioned that this is not always a common practice among regulators.

It was noted that there are different approaches for ensuring the safety functions and cybersecurity features for computer based instrumentation and control (I&C) systems. These aspects are considered as one of the main safety–security interfaces when considering the design of evolutionary and innovative reactors, which extensively utilize computer based I&C. It was noted that the safety functions and cyber security features for digital I&C systems need to be designed and implemented in such a way that prevents them from compromising one another. The discussions also emphasized the importance of regulators to enable application of risk informed approaches to support the design and implementation of safety and security measures for these systems.

Consideration of all 3S for advanced reactor designs is expected to add significant benefits for safeguards in addition to traditional safety and security benefits. In particular, it will allow for more efficient and effective safeguards inspections, facilitate joint-use equipment that can be used for both safeguards and commercial purposes, further reducing safeguards costs, increasing accessibility, and reducing the dependency on onsite inspections for safeguards monitoring. Presentations recognized that there is limited knowledge of international safeguards in design companies of certain countries and a lack of uniform implementation of international safeguards can lead to confusion and inconsistencies, especially when implementing safeguards in the design stage, as safeguards are often viewed as an operational concern rather than a design driver. These challenges are also coupled with reluctancy of companies to share details about their designs for proprietary or commercial reasons. However, the systematic consideration of nuclear safety, security, and safeguards is best achieved if it is done at an early design stage. This enables the identification and incorporation of safety, security, and safeguards measures into the design with systematic consideration of their interfaces. This approach is significantly more effective and efficient than attempting to retrofit these measures into an existing design.

Presentations held during the 3S sessions emphasized the need to utilize the time available to address safeguards challenges for the new designs. New safeguard approaches with potential customized verification techniques for some of the new designs will need to be developed, verified, and validated before being deployed. Time is also necessary to provide training to different stakeholders who are not familiar with safeguards, such as designers, operators, and state authorities in emerging nuclear energy States. The session discussions considered the lack of comprehensive guidance, education and training activities on nuclear safety, security, and safeguards by design as a major challenge that needs to be addressed. Presenters emphasized the importance of providing adequate training and education to designers, operators, and regulators to ensure that they have the necessary knowledge and skills to address these issues effectively. In general, it was concluded that risk informed approaches are being mostly applied for safety, however, they can be successfully applied to all 3S.

Proposals for a systematic approach for the assessment of the interface between safety and security were presented and discussed during the conference session. The papers in particular included guidance on how to address the assessment of the interface with the objective of optimizing as much as possible to avoid retrofit design work. It was mentioned that building trust is a key to public acceptance and support for innovative technologies. It is important to engage with the public early and often. By engaging with the public, designers and regulators can demonstrate that they have carefully considered the safety, security, and safeguards aspects of the technology, and can address any concerns that may arise. This can help to build trust and support for the technology and can ultimately contribute to its successful deployment.

During the discussions it was concluded that the IAEA needs to play a key role in promoting this approach and providing support to all stakeholders.

## 6. TOPIC 2 - ENHANCING SAFETY BY INNOVATIVE DESIGN FEATURES

### 6.1. DEFENCE IN DEPTH

In accordance with the international consensus reflected in provisions of IAEA safety standards, the primary design measure for preventing accidents in a NPP and mitigating the consequences of accidents if they do occur is the application of the concept of DiD (see 5.3). DiD is implemented primarily through the combination of a number of consecutive and independent levels of protection that would have to fail before harmful effects could be caused to people or to the environment. The independent effectiveness of the different levels of defence is recognized in IAEA safety standards as a necessary element of DiD.

Discussions held during this conference session confirm the common understanding that DiD remains the fundamental design concept for NPPs of existing and advanced designs (including SMRs). The challenge is lack of experience of practical implementation of DiD for innovative reactor designs. Presented papers discussed different aspects of the implementation of the DiD concept to specific types of advanced reactor, in particular levels 4 and 5 of DiD, independence of DiD levels for designs with passive systems, and accounting for technology-specific internal hazards.

Possible approaches to DiD implementation in innovative designs were presented and discussed in particular, lines of defence methodology. It was concluded during discussions that DiD assessment for innovative reactors will benefit from an integrated application of deterministic and probabilistic considerations. Non-prescriptive, performance based approaches to regulation could be considered as one of the options to enable acceptance of innovative DiD implementation. The need for practical guidance on integrated application of deterministic and probabilistic approaches for DiD assessment was stressed.

The discussion shows that there is a need for practical guidance for assessing the sufficiency of design measures aimed to eliminate cliff edge effects. Discussions showed that assessment of the need for design measures that eliminate cliff edge effects could be based on three aspects:

the independence between DiD levels, the significance of the consequences of cliff edge effects, and the likelihood of the cliff edge effect occurring.

## 6.2. TRANSPORTABLE NPP DESIGNS

Transportable NPPs are recognized as one of the directions of innovative NPP development, which is expected to bring several advantages for Member States utilizing this technology. During this conference session the IAEA Secretariat shared information with participants on completed and ongoing activities in IAEA in relation to transportable NPPs. Papers devoted to floating NPPs were presented by participants.

Presented papers and the results of the discussions show that several Member States acknowledge that there is a need for developing an international regulatory framework for floating NPPs due to the differences between these plants and the provisions of the existing framework for transport of radioactive material. Some of the methods for safety regulation and demonstration presented and discussed were different from those used for conventional NPPs (in particular, the methods to implement the DiD concept). It was noted in some of the papers that the closest analogue could be the regulatory framework for self-propelled vessels with nuclear reactors, which in many respects could be directly applicable to the floating NPPs.

Proposals for a systematic approach to the safety of floating NPPs based on the application of the DiD concept were presented and discussed. Again, it was concluded that the DiD implementation for floating NPPs would be more efficient through combined application of deterministic and probabilistic considerations.

## 6.3. DESIGN SAFETY FEATURES

This conference session provided presentations on a range of key areas of innovation in the design of evolutionary and advanced reactors, reflecting their role in ensuring nuclear safety.

Some papers on innovative design features in evolutionary reactor designs covered compact pressurized water reactors (PWRs), which integrate the main components such as steam generators and pressurizer into the reactor vessel, and often intend to utilize natural circulation as part of their safety case. To validate these design features, design proponents are focusing their efforts on advanced modelling and research and development programmes. The papers indicated that a range of components such as passive heat pipe devices and cold source systems are being proposed to deliver heat dissipation under accident conditions in PWRs and their performance has been studied through simulation and numerical analysis. The use of numerical modelling analyses was also presented as a means to develop correlations between fuel cladding material properties and endurance times, to indicate favourable fuel cladding materials that could provide accident tolerant fuels in new reactors. As devices and components are proposed to enhance the safety performance of evolutionary designs, presenters reflected on the value of standardization, for example, with calls for standardizing the design and performance expectations of key safety components such as Emergency Core Cooling System (ECCS) strainers in PWRs.

A significant number of papers covering design safety features focused on the specific research and development efforts of innovative reactor designs. Presenters emphasized the need for experimental results to underpin the development of molten salt reactors, where the physical properties of fuel and intermediate circuit salts are being established through testing. Similarly, the reprocessing techniques and reactor structural materials that would be appropriate for molten salt reactors were discussed.

In the context of design development for deployment of high temperature gas reactors, presentations ranged from numerical analyses aimed at extracting key safety insights such as the expected fuel and core responses to loss of coolant accidents in high temperature gas microreactors, to the efforts being undertaken in Member States wishing to deploy this reactor technology while capitalizing on modular build techniques. For example, a presentation outlined how the modular build of primary circuit vessels and pipework in a compact but full-scale mock-up could enable statutory inspections to be delivered using remotely operated devices.

Innovative designs based on lead cooled fast reactor technology were presented as part of this session. The presentations outlined how lead coolant behaviour and passive safety claims could potentially decrease reliance on high pressure containments and active component actuation. They also covered how material corrosion/erosion and lead freezing phenomena is being studied in test rigs. It is nevertheless important to reflect that DiD remains the main philosophy for ensuring nuclear safety and its demonstration in innovative reactor designs and this is a key area of focus not only in design development, but also in the development of safety standards. Key design requirements such as those in IAEA Safety Standards Series No. SSr-2/1 (Rev. 1), Safety of Nuclear Power Plants: Design[4] were developed with a focus on light water reactor (LWR) technology. Presenters showed that efforts continue to develop safety design approaches to fulfil regulatory requirements for sodium cooled fast reactors and lead cooled fast reactors. Key publications introduced in this session included the Safety Design Requirements and Guidelines developed through international cooperation under the auspices of the Generation IV International Forum (GIF).

Finally, it was noted that regulatory expectations and requirements in areas such as human factors engineering (HFE), which were previously based on LWR technology, are evolving towards technology agnostic, risk informed and performance based frameworks. The increasing role of risk informed regulatory approaches versus prescriptive approaches is considered fundamental in the deployment of innovative reactor technologies, given the significant variability and distinct safety features and components being proposed.

## 6.4. PASSIVE SYSTEMS

Passive safety systems are being proposed in both evolutionary and innovative reactor technologies, to deliver safety functions including decay heat removal, emergency coolant injection and, in gas fast reactor technologies, residual pressure retention. During this session, presenters provided visibility of the experimental and modelling programmes currently underway to produce the validation data needed to underpin the introduction of passive systems as part of the designs and their requisite safety justifications.

The presentations acknowledged the potential for interferences between passive system features (e.g. between two sets of passive valves, where actuation of one can cause unwanted consequences in the other one) and these interactions and potential performance issues were

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Nuclear Power Plants: Design, IAEA Safety Standards Series No. SSR-2/1 (Rev. 1), IAEA, Vienna (2016).

generally identified as an area requiring further consideration. Similarly, there were calls for uncertainty assessments to be undertaken so that passive safety system performance and reliability are better understood. In this context, a presentation documented the uncertainty assessments which have been proposed and demonstrated for compact SMRs based on LWR technology. As part of the discussions, experimental studies were also recognized as needed for the characterization of extremely infrequent scenarios that are not generally provided for in NPP designs. Such experimental studies would also be needed for better understanding the performance of new passive safety features applied in innovative designs for which there is little or no operational experience. An additional area of focus during the presentations was the need for understanding the long term operation of passive safety systems (including systems provided for transition from controlled plant state to safe state in the course of an accident). This was acknowledged as an essential part of the safety demonstration for evolutionary and innovative reactor designs, and there was recognition that modelling could provide a valuable route to increase confidence, notwithstanding the need for experimental evidence.

The need for both experimental and modelling capability to demonstrate the performance of passive systems in advanced reactor concepts was considered essential for the eventual successful safety demonstration and licensing of such designs. During the presentations, the research and development programmes being implemented by design proponents were covered in detail. It was considered that research efforts were particularly needed to support implementation of passive safety features in innovative reactor designs, and how these were being met through the construction and use of experimental rigs in national nuclear laboratories. Examples of test facilities discussed included natural convection water and molten salt loops, heat pipes in LWR SMRs and alkali metal systems.

Finally, the presenters reflected that, in addition to the research and development needed to underpin the introduction of passive systems in NPP designs, there is a need for regulatory bodies and their technical support organizations (TSOs) to ensure that they have the capability and capacity for assessing the design and safety demonstration of such systems (as part of the NPPs overall safety justification to meet the requirements of the Member States' regulatory framework).

## 7. TOPIC 3 - SUPPORTING INTEGRATED DECISION MAKING THROUGH SAFETY/RISK ANALYSES

### 7.1. DETERMINISTIC SAFETY ANALYSIS

The conference covered a wide range of topics related to DSA and safety demonstration of evolutionary and innovative reactor designs, with presentations from a wide range of stakeholders and Member States. The papers presented accident analysis methods and results for a number of advanced plants, safety analysis examples including for external hazards, advanced methods for modelling, and use of risk informed approaches in support of DSA. These topics were presented for a range of reactors including advanced LWRs, Sodium cooled fast reactors (SFRs), and molten salt reactors (MSRs), as well as technology-inclusive approaches that can be applied to any reactor type.

An area of particular focus was the need to integrate both DSA and PSA in support of the overall safety case for advanced reactors. This begins with sharing a common list of postulated initiating events (PIEs) which are used as a basis for both the DSA and PSA. The PSA can then be used to support the PIE categorization, demonstration of the levels of independence of DiD levels, demonstration of practical elimination for large or early releases, analysis of multi-module or multi-unit configurations, and other areas. Related to practical elimination, there was significant discussion in several sessions stressing the need for broader international consensus on the demonstration of practical elimination for advanced reactors given some inconsistency between Member States in this area.

Challenges in the development of safety analysis for advanced reactors involve the analysis techniques that have been developed for current reactor designs and a lack of operating experience for new reactor design features, such as passive systems, new fuel types, or new reactor coolant types. This issue includes the uncertainty related to simulation and modelling codes used to model the design features discussed above, including the limited industry experience in applying the codes, and the limited test data that support the validation of the codes. This is discussed more thoroughly in other areas of the conference, but in the safety analysis presentations, the discussion focused on methods and approaches given the uncertainty that results from the limited experience. The discussion included a range of viewpoints, including both designer and regulatory viewpoints. Related to this, several presentations focused on plans and techniques to reduce the overall uncertainty of the analysis, as well as approaches to support the safety demonstration of advanced reactors during the design and licensing process. Insights from other industries such as the aeronautics and space industry were the subject of one presentation.

Methods and techniques used to support safety analysis involving unique fuel types, including molten/liquid fuels, were discussed in several presentations. This included the discussion of alternate parameters which could be measured and used in reactor control to ensure the reactors are kept within acceptable limits during transient or accident conditions. Validations of accident progression models are needed to support this modelling and analysis, including the support for mechanistic source term estimates. It was noted during the conference that this additional validation, including regulatory acceptance of the validation, will result in longer licensing times in some cases. The use of additional safety margin in support of the DSA was also discussed as one technique to address uncertainty in the safety analysis results.

The use of computer codes in support of passive systems was presented in several papers. Proposals for improved integration and coupling of codes were presented, given different models may be utilized for passive systems, reactor thermo-hydraulics and mechanistic source terms.

Finally, the harmonization of approaches for analysis of internal events, internal hazards and external hazards was noted as an area of improvement with due attention to be paid to demonstration of the links between the hazards and plant states in the safety demonstration of evolutionary and innovative reactor technologies.

## 7.2. PROBABILISTIC SAFETY ANALYSIS AND RISK INFORMED DECISION MAKING

There were a significant number of conference sessions on PSA and risk informed decision making (RIDM), which covered a wide range of technical issues and methodology development supporting evolutionary and innovative reactor designs. The general conclusion is that the use of risk informed approaches to support the safety demonstration is expanding in the context of innovative reactors.

A broad area discussed in Section 6.1 that was covered in more detail in the PSA discussions involved the use of PSA in support of the DSA. This included several presentations related to the use of PSA in support of classification of structures, systems and components (SSCs). These presentations covered the Licensing Modernization Project approach being applied in the U.S, as well as verification of SSC classification using the PSA under IAEA Safety Standards Series No. SSG-30, Safety Classification of Structures, Systems and Components in Nuclear Power Plants[5]. Both approaches emphasize the need to better align the risk significant SSC output from the PSA and the SSC classification supported by the DSA.

Related to the above, several presentations provided results of a risk informed safety strategy, where the PSA is utilized to inform the plant safety case. As noted in the Section 6.1, the initial step includes the harmonization of the PIE list that supports both the PSA and DSA, followed by the harmonization of the DiD model supporting each analysis.

Modelling of passive or inherent plant features, and integration into the PSA/RIDM, was covered in several presentations, beyond those discussed in the separate Passive Reliability sessions discussed in Section 5.4. As noted in several presentations, the use of passive or inherent safety features results in significantly lower risk for advanced reactors but can result in increased uncertainties. One aspect of this is the significant reduction in risk following a loss of offsite power or station blackout event. These events are of general concern following a significant external hazard event, such as a large seismic event. Modelling of other plant features in the PSA was also discussed in several presentations including the modelling of first of a kind features, digital instrumentation, and components with limited operating experience. Related to digital instrumentation, the need to improve modelling of software common cause failures (CCFs) was noted, especially given the increased use of automation and the goal for decreased use of operator actions to ensure both short term and long term safe shutdown is maintained. Although advanced reactor designs are less reliant on operator actions, the longer time frames involved in some accident scenarios present a challenge for the human reliability analysis, including the modelling of dependency between operator actions.

The use of PSA supporting emergency preparedness and EPZ evaluation (siting) was discussed in several presentations. Many innovative reactor designs utilize a smaller source term and

---

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Classification of Structures, Systems and Components in Nuclear Power Plants, IAEA Safety Standards Series No. SSG-30, IAEA, Vienna (2014).

lower overall plant risk to support a reduced size of EPZ, potentially limiting the EPZ to the site boundary and making these designs more attractive.

Several aspects of RIDM supporting regulatory decisions were presented and discussed. There is a continued need for PSA standards and guidance documents, with the need to ensure these documents are improved as the use of PSA increases for innovative reactor licensing. This development includes the need to facilitate the use of risk informed approaches in various directions (e.g. for SSC classification, selection of PIEs for DSA, categorisation of plant states, assessment and implementation of DiD).

Finally, the regulatory challenges of evaluating evolutionary and innovative reactor designs given the lack of operating experience and overall uncertainty with expanded use of passive and inherent safety features were presented.

Increased use of PSA to support reliability, availability, maintainability and inspectability (RAMI) goals as well as generation risk assessment (GRA) modelling. RAMI goals are required under the US Licensing Modernization Project process, used to ensure the overall plant risk remains below the plant risk goals used to evaluate the SSC classification and DiD adequacy. GRA is being applied to evolutionary and innovative reactor designs in support of design efforts ensuring high plant availability even for plants with limited operating experience.

Finally, several presentations noted the need to perform Level 3 PSA (offsite consequence) to support RIDM, especially for non-LWR designs. This includes the application of the US Licensing Modernization Project process as well as in applying PSA in the evaluation of emergency planning and EPZ discussed above. It was noted that development of IAEA guidance for Level 3 PSA is needed.

### 7.3. SEVERE ACCIDENT MANAGEMENT

Advances in modelling and evaluation of severe accidents for advanced reactors was presented in several papers. This included the experiments and development of analytical programmes used to demonstrate the effectiveness of passive and inherent features, such as those used in the ACP100 SMR design. The development of state of the art computer codes including both modelling and simulators was presented. The use of recent severe accident research to improve models was discussed, such as modelling of both in-vessel and ex-vessel corium behaviour and coolability. The verification of severe accident management guidelines (SAMGs) was discussed as well as the use of severe accident analysis in support of SAMG training.

In general, the problem of clear understanding of the severe accident conditions for innovative reactors was specifically noted. Efforts are needed in this area to harmonize the severe accident definitions and the approaches to severe accident management of innovative reactor designs (e.g. non-water-cooled reactors).

### 7.4. EXTERNAL HAZARDS

Lessons learned from recent analysis of external hazards for evolutionary and innovative reactor designs were discussed in several papers. This included the lessons learned included in the clearinghouse topical operating experience report on external hazards[6] for use in the design of new reactors. Challenges related to evaluation of external hazards for innovative reactor designs were discussed and the importance of external hazards analysis in supporting SMR siting was highlighted. It was noted that major modifications may be necessary to adapt specific designs to country specific regulatory frameworks and site-specific conditions, which creates issues for design standardization.

While discussing the potential for the optimization of advanced reactor designs against external hazards it was noted that optimization needs to be done as early as possible in the design stage. It will allow the designers to use the insights for the design improvements in terms of protection against external hazards.

During the discussions it was noted that the selection of beyond design basis external hazards used for the demonstration of the adequacy of reactor designs represents a challenge given the uncertainties associated with low frequency events. The treatment of these low frequency events in the safety case for evolutionary and innovative reactor designs was discussed. Risk informed, performance based techniques were found to represent promising approaches to a systematic treatment of low frequency external hazards in safety demonstration of plant designs. The limitations and challenges of those techniques are related to the accuracy of the associated data and analyses.

It was also noted that the existing operational experience feedback analyses provide high level lessons learned about external hazards to be considered in the design or the protection of equipment important to safety. These lessons learned could be applicable for some of the innovative reactors (e.g. LWRs).

## 7.5. MULTI-UNIT AND MULTI-MODULE RISK ANALYSIS

The presentations on Multi-Unit (MU) and Multi-Module PSA included a presentation on the recently published IAEA Safety Report Series No. 110[7] on with MU PSA methodology. It was noted that this approach generally applicable for all types of reactor and could be applied for multi-module risk analysis. The case study to illustrate and support the methodology is focused on an LWR type reactor.

It was noted that continued development and study of non-LWR PSAs is needed, given the nature of passive and inherent safety features in non-LWR reactors. Additionally, as noted in IAEA Safety Report Series No. 110[8], the continued development and case studies of Level 2

---

[6] ZERGER, B. et al., European Clearinghouse: Report on External Hazard related events at NPPs, Summary Report of an European Clearinghouse Topical Study, EC JRC, 2013 https://publications.jrc.ec.europa.eu/repository/bitstream/JRC83587/ldna26104enn.pdf

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, Multi-unit Probabilistic Safety Assessment, Safety Reports Series No. 110, IAEA, Vienna (2023).

[8] INTERNATIONAL ATOMIC ENERGY AGENCY, Multi-unit Probabilistic Safety Assessment, Safety Reports Series No. 110, IAEA, Vienna (2023).

and Level 3 MU PSA are needed. The development of unique risk metrics for Level 2 and Level 3 MU PSA was discussed during the session, including the metrics that can measure the overall public risk from a MU release.

Several presentations noted that for many of the SMR designs, the resulting sites may contain numerous units or modules. As a result, the site risk may be dominated by MU releases from a beyond design basis external hazard event, such as a seismic event. This is an important aspect for developing an overall safety case for a site, although there is a noted gap in the treatment and guidance in safety case development for a MU site.

# 8. TOPIC 4 - ACCELERATING INNOVATIONS FOR SAFETY ASSESSMENT THROUGH ADVANCED SIMULATION AND MODELLING, AND EXPERIMENTAL PROGRAMMES

## 8.1. SIMULATION AND MODELLING

Computational codes capable of performing analytical and numerical simulations are used extensively in the design and safety analyses of nuclear reactors. For this purpose, requirements and expectations on the development and use of analytical and numerical methods are mostly derived from high level principles associated with the applications of the codes to support the safety case and safety analysis. In all cases, regulators expect a licensee to provide evidence of sufficient validation and verification of the codes and methods used to support a safety case. Moreover, sensitivity and/or confirmatory analyses may be requested to examine the behaviour of active and passive systems under different parameter ranges.

The papers and discussions under this sub-topic included the development and validation of simulation codes, innovative computer tools developed for training (e.g. safety culture in sodium reactors), and a code for the design and simulation of a hybrid backup electrical system for nuclear installations which considered technical, economic and environmental criteria. Moreover, harmonized mechanical codes and standards as well as surrogate models, that may benefit from artificial intelligence (AI) approaches, are being developed for innovative reactors such as SMRs.

The typical regulatory expectation is that the licensee will provide evidence of sufficient validation and verification of the codes and methods used to support a safety case. To meet regulatory expectations, the verification of computational codes and associated methodology is usually performed by comparison of the results with already benchmarked codes and available publicly accessed literature. More efforts are needed for verification and validation and uncertainty quantification for innovative reactors with first of a kind features and novel phenomenology.

Given the diversity of advanced reactors under development, several well-instrumented experiments are being performed, in the framework of collaborative projects (EU, OECD, IAEA), with the aim of providing data for the validation of safety analytical tools and reducing the corresponding uncertainties. These experiments address different topics related to advanced reactors, such as natural circulation in passive systems in SMRs, stability and characterisation of Xe in High Temperature Engineering Test Reactor (HTTR) neutronics, or the performance of the containment venting system to capture iodine, etc.

To ensure the completeness of the experiments performed to cover the operating and accident conditions of innovative reactors, collaborative research programmes are needed. The collection and sharing of the results of these experiments will allow the quantification of uncertainties and the development of international benchmarks that will help to improve the validation of simulation tools.

In addition, the preservation and dissemination of experimental data and tools developed can accelerate the development of innovative reactors and the training of a new generation of engineers.

For the above reasons, during the discussions it was highlighted that there is a need to develop an international simulation and modelling database on innovative reactors and SMRs.

## 8.2. ARTIFICIAL INTELLIGENCE (AI)

The review of machine learning applications for nuclear safety highlighted the slow adoption of the technology in this sector due to several constraints, such as strict regulations, high safety standards and intellectual property. In addition, the review also highlighted the lack of large datasets of training data, needed for efficient and sophisticated algorithm development. This lack of data can be overcome by using verified and validated simulation and computational tools, especially for accident scenarios. As the computational cost can be prohibitive, collaborative research and good data management were recommended.

Within the requirements from regulations and safety standards, AI is gradually being adopted in the nuclear industry. Currently, the popular applications of AI in the industry are focussed on prediction of material proprieties and severe accident management. Broad opportunities exist for the potential use of AI in advanced and innovative reactors e.g. system design, plant operation, inspections and maintenance as well as safety and risk analysis. Thus, international efforts to share data, algorithms and tools are needed to help the further development of AI nuclear applications.

IAEA ongoing efforts on AI for safety of evolutionary and innovative reactors have been welcomed by the community.

## 9. CONFERENCE CONCLUSIONS AND INSIGHTS

TIC2022 generated an increased understanding among Member States of the safety approaches and practices used for evolutionary and innovative reactor designs and their licensing strategies. It also provided IAEA with valuable insights for its further activities related to the safety of evolutionary and innovative reactor designs. In particular, the feedback from the conference is important in tailoring the IAEA efforts on capacity building activities, strengthening advisory and peer review services, and further enhancing international cooperation for those reactors.

The main outcomes, observations and insights of the conference have been summarized by the Conference President, Rapporteurs and the IAEA Scientific Secretaries. The key "Call for Actions" of the conference were summarized by the Conference President during the TIC2022 closing session, as follows:

**Call for Action 1 - Robust safety demonstration: Member States** to ensure robust safety demonstration of evolutionary and innovative reactors and the **IAEA** to support MSs with the reviews against IAEA safety standards (peer review missions for these reactor designs)

**Call for Action 2 – Harmonization and standardisation: Member States** to continue efforts on harmonization and standardisation. **Regulators** to be open-minded and to advance their regulatory frameworks to address new technologies in a collaborative manner. **Industry** to focus on codes, standards, and share the experimental programmes.

**Call for Action 3 – International collaboration: Member States** to intensify international cooperation about safety of innovative technologies and **IAEA** to facilitate this process. Multilateral cooperation needs to benefit from lessons learned from bilateral and trilateral ones.

**Call for Action 4 – 3S interfaces in design: Member States** to ensure that safety, security and safeguards measures are implemented by design in an integrated manner considering their interfaces. **Regulators** to adopt 3S considerations in the regulatory framework. **Industry** to integrate 3S by design in early design stages. **IAEA** to provide guidance and support.

**Call for Action 5 – Experimental data and tools: Member States** to preserve and disseminate experimental data and tools to support development of innovative reactors and their safety assessments.

**Call for Action 6 – Integrated use of DSA and PSA: Member States** to enhance integration of deterministic and probabilistic approaches for a wide range of safety topics of evolutionary and innovative reactor designs (such as DiD, SSC classification).

A final statement by the Conference President, Ms Rosa Sardella, during the closing session of the conference concluded that the topics discussed during the event demonstrated the need for platforms for future discussions and the importance of attracting all relevant stakeholders to those events. The 8th International Conference on Topical Issues in Nuclear Installation Safety will be held in 2026.

## APPENDIX 1. SCIENTIFIC PROGRAMME COMMITTEE

### PRESIDENT OF THE CONFERENCE

| | |
|---|---|
| R. Sardella | ENSI, Switzerland |

### SCIENTIFIC PROGRAMME COMMITTEE MEMBERS

| | |
|---|---|
| P. Webster *(SPC chair)* | CNSC, Canada |
| W. Metwally *(SPC co-chair)* | University of Sharjah, UAE/ORNL, United States |
| A. Bentaib | IRSN, France |
| A. Gomez Cobo | IAEA |
| B. Smith | USNRC, United States |
| D. Henneke | GE-HITACHI, United States |
| D. Lisbona | ONR, United Kingdom |
| G. Rodriguez | CEA, France |
| H. Rhein | European Commission |
| I. Sokolova | ROSTECHNADZOR, Russian Federation |
| K. Epskamp | European Nuclear Society |
| K. Qureshi | PIEAS, Pakistan |
| M. Tuomainen | STUK, Finland |
| N. Subrtova | UJD, Slovakia |
| T. Liu | CNPO, China |
| S. Kubo | JAEA, Japan |
| V. Rouyer | OECD, Nuclear Energy Agency |
| L. Williams | Imperial College London, United Kingdom |

### IAEA SCIENTIFIC SECRETARIES

| | |
|---|---|
| S. Poghosyan | NS/NSNI/SAS, IAEA |
| T. Jevremovic | NE/NENP/NPTDS, IAEA |

# APPENDIX 2. SECRETARIAT OF THE CONFERENCE AND RAPPORTEURS

## SECRETARIAT OF THE CONFERENCE

| | |
|---|---|
| S. Poghosyan | Scientific secretary (SAS/NSNI/IAEA) |
| T. Jevremovic | Scientific secretary (NPTDS/NENP/IAEA) |
| T. Danaher | Conference coordinator (CS/MTCD/IAEA) |
| F. Parada Iturria | Scientific support (SAS/NSNI/IAEA) |
| G. Choi | Scientific support (SAS/NSNI/IAEA) |
| L. Videla | Scientific support (SAS/NSNI/IAEA) |
| X. He | Scientific support (SAS/NSNI/IAEA) |
| S. Emmanouilidou | Administrative support (SAS/NSNI/IAEA) |

## CONFERENCE RAPPORTEURS

| | |
|---|---|
| B. Smith (USNRC, US)<br>J. Yllera (IAEA) | **Topic 1.** Applying safety approaches and standards for evolutionary and innovative reactor technologies |
| D. Lisbona (ONR, UK)<br>M. Lankin (IAEA) | **Topic 2.** Enhancing safety by innovative design features |
| D. Henneke (GE-HITACHI, US)<br>M. Gajdos (IAEA) | **Topic 3.** Supporting integrated decision making through safety/risk analyses |
| A. Bentaib (IRSN, France)<br>H. ur Rehman (IAEA) | **Topic 4.** Accelerating innovations for safety assessment through the advanced simulation and modelling, and experimental programmes |

## SUPPLEMENTARY ELECTRONIC FILES

The "CN-308 Supplementary Electronic Files" consist of all the papers presented at the International Conference. These files are divided into five volumes, each corresponding to a different conference topic and the firth volume for the E-session. The papers are arranged according to the specific subtopic and order of the session in which they were presented.

To facilitate access and navigation, the supplementary electronic files are organized in the following sequence of five volumes:

### VOLUME 1

### TOPIC 1. APPLYING SAFETY APPROACHES AND STANDARDS FOR EVOLUTIONARY AND INNOVATIVE REACTOR TECHNOLOGIES

**Regulatory & Licensing**



**International collaboration & Harmonization**



**Safety Approach**

ID76 NUWARD safety approach, implementing SMR specifics and preparing international deployment

ID37 Towards innovative reactors licensing – ALFRED approach

ID99 Toward developing a novel combined licensing & safety approach for advanced nuclear reactors based on the international nuclear safety and maritime frameworks - case study of the CMSR power barge

**Safety, Security and Safeguards interfaces (3S)**

ID70 Considering international safeguards during the design of advanced reactors and interfaces with safety and security

ID81 Safety, security and safeguards working together in a modernised generic design assessment

ID184 Lessons learned from exploring safety, security, and safeguards interfaces in advanced and small modular reactor technologies

ID173 Using the INPRO methodology for a sustainability assessment in safety, safeguards, and security (3s)

ID123 Application of the objective provision tree tool for the safety-security interface assessment

ID25 Nuclear energy agency's consensus position on the impact of cyber security features on digital instrumentation and control systems important to safety at nuclear power plants –evaluation framework

ID24 U.S.A. regulatory efforts for cyber security of advanced reactors

## VOLUME 2

## TOPIC 2. ENHANCING SAFETY BY INNOVATIVE DESIGN FEATURES

**Defence in depth**

ID152 CAREM25: An integral methodological approach to coherently internalize defence in depth in the design process

ID103 Application of lines of defence (LOD) methodology for defence in depth implementation in the design of GEN4 reactors

ID83 Regulatory perspective on the application of the defence in depth concept to innovative reactor technologies

ID155 Design measures aimed at eliminating cliff edge effects as a necessary condition for effectiveness of plant defence in depth

**Transportable NPP designs**

ID100 Safety approaches for the CMSR power barge

ID147 Floating nuclear power units: safety assurance during transportation

| | |
|---|---|
| ID169 | INPRO studies on transportable nuclear power plants and modules and key legal issues for their regulations |

**Design safety features**

| | |
|---|---|
| ID26 | Development of the first Russian research molten salt reactor for technology trial of minor actinides burning. Nuclear Safety Features |
| ID121 | Research on heat pipe conduction device of containment dome |
| ID122 | Material performance metrics for accident tolerant fuel cladding in pressurised water reactors |
| ID119 | Application of passive cold source system in Hualong nuclear power plant design |
| ID29 | Evaluation of the basic neutronics and thermal-hydraulics for the safety case of the advanced micro reactor (AMR) |
| ID40 | U-battery 10 Mwth HTGR advanced modular reactor enhancing safety through innovative design |
| ID131 | Conceptual design of Mitsubishi small modular reactor |
| ID84 | Technology-inclusive human-system considerations for advanced reactors |
| ID60 | Safety design approaches for future SFRS in Japan |
| ID118 | Standard study of the technology and safety performance evaluation on emergency core cooling system strainer |
| ID107 | GIF LFR safety design criteria |
| ID127 | Development of safety design criteria and safety design guidelines for generation IV sodium cooled fast reactors |
| ID144 | An integrated design approach to address safety of the Westinghouse LFR: an innovative pool-type, liquid lead cooled fast reactor |

**Passive systems**

| | |
|---|---|
| ID54 | Evaluation of efficiency of passive heat removal system in VVER-1200 under beyond design basis accidental conditions |
| ID133 | Innovative passive safety features of the HEFASTO reactor concept |
| ID199 | An experimental programme for ACP100 passive containment air cooling system |
| ID189 | Development of experimental and modelling capabilities and tools at Canadian nuclear laboratories for investigations on inherent and passive safety designs of advanced reactor concepts |
| ID57 | The effect of intermittent passive heat removal on HTGR conduction cooldown performance |

ID148 Experimental and computational research of the containment passive emergency pressure decrease system in the floating NPP with reactor KLT-40s and universal nuclear-powered icebreaker with reactor RITM-200

ID186 Uncertainty assessment of a CAREM25 passive safety system: model-lifecycle management study case

ID129 Thermal hydraulic analysis of a novel passive containment cooling system concept

## VOLUME 3

## TOPIC 3. SUPPORTING INTEGRATED DECISION MAKING THROUGH SAFETY/RISK ANALYSES

### Safety Demonstration

ID30 A comprehensive thermo-hydraulic neutronic and safety analysis of a 100Mwth pebble bed reactor core

ID112 Application of objectives-driven assurance cases to system development in an evolving acquisition model

ID115 Internal flooding safety assessment of ACP100 reactor plant based on CNIFA

ID196 Steps toward efficiently demonstrating adequate MSR safety

ID124 GIF integrated safety assessment methodology (ISAM) and guidance for its implementation for novel advanced reactors

ID52 Potential gaps in safety demonstration methods for LW-SMR identified in the ELSMOR project

ID73 Advances in knowledge, modelling and methods to support safety demonstration of conventional and advanced nuclear fuels in the OECD/NEA working group on fuel safety

### Deterministic safety analysis (DSA)

ID3 Issues and needs in applications of deterministic safety analysis for demonstrating safety of evolutionary and innovative nuclear power plants

ID105 Determination of temperature condition of absorbing elements for design basic conditions and design extension conditions of nuclear power plants

ID114 Numerical analyses of design extension conditions for sodium cooled fast reactor designed in Japan

ID149 Integrated design analyses of beyond-design-basis accidents at VVER-1200, including fuel severe damage

**Probabilistic safety assessment and risk informed decision making (PSA & RIDM)**

| | |
|---|---|
| ID139 | The publication and endorsement of the ASME/ANS Probabilistic Risk Assessment standard for advanced non-light water reactor nuclear power plants |
| ID128 | Changes in PSA models to support licensing of advanced Non-Light Water Reactors |
| ID98 | Verification of SSC safety classification according to IAEA SSG-30 functional approach: benefits of DSA and PSA integration |
| ID126 | Natrium reactor SSC classification using the licensing modernization project (LMP) process |
| ID193 | Risk informed safety strategy and fault evaluation for the GE HITACHI BWRX-300 |
| ID202 | Insights on application of some probabilistic considerations for licensing of new nuclear power plants |
| ID41 | Evolution in level 3 probabilistic safety assessment methodology for the UK EPR |
| ID164 | Argentinian regulatory criterion proposal for mission time in events trees for L1 PSA for new nuclear power reactors |
| ID134 | Arkadia-safety, an overall risk assessment simulation tool for integrated risk informed and performance based decision making |
| ID93 | GIF framework for risk informed approach for safety design and licensing of novel advanced reactors |
| ID58 | Integrated RAMI for advanced nuclear power plants |
| ID175 | Incorporation of passive system functional reliability in a probabilistic safety assessment |
| ID36 | Application of probabilistic method in the EPZ determination of SMR |
| ID94 | Insights for risk informed approaches to sizing emergency planning zones |
| ID162 | Challenges in defining emergency planning zones for small modular reactors and advanced reactors: review of Canadian practices and research at Canadian nuclear laboratories |
| ID135 | An alternative emergency preparedness regulatory framework for small modular reactors and other new technologies |
| ID97 | Synergizing deterministic and probabilistic safety analyses – a holistic approach to safety at Leibstadt NPP, Switzerland |
| ID85 | Application of the Level 1 PSA model in various regulatory processes and challenges faced during their execution |
| ID110 | U.S. nuclear regulatory commission guidance on the acceptability of probabilistic risk assessment used in regulatory decision making for Non-Light-Water Reactors |
| ID168 | Contextual integrated risk informed decision making |

**Severe accident management**

ID46 The development and validation of the accident prevention and mitigation strategy for the ACP100 modular small reactor

ID172 Development and application of verification and exercise platform for China nuclear power severe accident management guidance to strengthen the safety training through simulator

ID50 NUGENIA/TA2 recent achievements in severe accidents research

ID67 Practical application of uncertainty and sensitivity analysis methodologies for the analysis of severe accidents in VVER reactors

ID95 Uncertainty and sensitivity analysis of the PWR and SMR by means of severe accident codes in the framework of the IAEA CRP I31033

ID33 Computer aided design and simulation of professional hybrid electrical energy backup system for nuclear facilities

**External Hazards**

ID64 Main lessons learned from the clearing-house topical operational experience report (TOER) on external hazards and their possible use for the design of new reactors

ID78 External hazard challenges for evolutionary and innovative reactor designs

ID181 The regulatory treatment of low frequency external events as part of a risk informed, performance based approach

**Multi-unit & multi-module risk analysis**

ID145 Multi-unit probabilistic risk assessment (MUPRA) for the prism sodium cooled fast reactor

ID66 Probabilistic safety assessment of multi unit site of nuclear power plant

## VOLUME 4

## TOPIC 4. ACCELERATING INNOVATIONS FOR SAFETY ASSESSMENT THROUGH THE ADVANCED SIMULATION AND MODELLING, AND EXPERIMENTAL PROGRAMMES

**Simulation & modelling**

ID104 Regulatory perspectives on analytical codes and methods for advanced reactors

ID35 IAEA simulation and experimental analyses network information system (SANIS) database: severe accidents experimental facilities, codes and education and training tools

| | |
|---|---|
| ID56 | The Russian approach to the regulatory review of computer programs used for multi-physics modelling and safety analysis of innovative nuclear installations |
| ID28 | The OECD/NEA working group on the analysis and management of accidents (WGAMA): advances in codes and analyses to support safety demonstration of nuclear technology innovations |
| ID160 | State of the art of IRSN's studies regarding fuel behaviour during LOCA |
| ID171 | Development of a structural integrity model for a postulated uniform wall thinning wear degradation of the steam generator tubing in the SMART100 small modular reactor |
| ID154 | Calculation of the neutron parameters for the accelerator driven subcritical reactor using pb and Pb-Bi mixtures as both target and coolant |
| ID86 | The finite element neutronics code fennecs for the safety assessment of SMRs, micro reactors and other innovative concepts |
| ID69 | Using calibrated water data for preliminary validation of the SRT code for advanced reactors |
| ID106 | Harmonizing mechanical codes & standards for innovative reactors |
| ID59 | New test plan about safety features of HTGR by using HTTR in JAEA |
| ID132 | Status of the independent validation of trace code for SMR safety analyses |
| ID8 | Thermal hydraulic codes validation for spent fuel pool conditions |
| ID190 | Revival of a practical sodium safety culture through experiential training |
| ID185 | Experimental investigation of iodine removal in a lab scale setup of filtered containment venting system |
| ID75 | Experimental investigation of liquid tin surface property safety features for potential application as a coolant in direct contact liquid metal fast reactors |
| ID92 | BWR severe accident uncertainty and sensitivity analysis in the framework of the IAEA CRP |
| ID137 | Practical application of uncertainty and sensitivity analysis methodologies for the analysis of severe accidents in VVER reactors |
| ID146 | Uncertainty and sensitivity analysis of severe accidents simulations at VVER in the framework of the IAEA CRP I31033 |
| ID161 | Natural circulation HERO-2 experiment simulations for the EU funded pastels project |
| ID91 | Long term effects and numerical simulation of radiolytic gas, non-condensable gas and boron transport for small modular light water reactors |
| ID188 | Development of multiphysics modelling capabilities for small modular reactors in Canada |
| ID39 | Status of the H2020 MCSAFER project-experimental and analytical investigations for the safety evaluation of water cooled SMRs |

ID157 Development of uncertainty and sensitivity approaches for the analysis of severe accidents in a small modular reactor

ID151 Uncertainty and sensitivity analysis of a CANDU 6 plant by means of severe accident codes in the framework of the IAEA CRP I31033: preliminary results

ID51 Recent improvements of ATHLET models for passive safety features of LW-SMR

ID45 System of design codes for the computational modelling of the lead cooled fast reactor cores

ID27 TRACE confirmatory analysis model development and validation in NUSCALE design

ID159 Enhanced safety of current and future nuclear plant using integrated mechanistic models and data-centric assessment of risk

**Artificial intelligence**

ID63 Towards a robust prediction of material properties by artificial intelligence and probabilistic methods

ID170 The design and application of the intelligent accident analysis system for the nuclear power plant

ID176 Machine learning applications for nuclear safety: An overview

## VOLUME 5

## E-SESSION CONTRIBUTIONS

ID53 Results of a quantitative comparison of different nuclear fuel cycles by their safety

ID71 The consideration of the independence of DiD and its application in HPR1000 design

ID101 Advanced programme for irradiation tests of fuel and materials to justify safety of evolutional and innovative designs for nuclear reactors

ID167 Multi agent systems application concept for enhancing reactor safety and operations in an innovative SMR

ID178 Reliability-based optimisation with nuclear data uncertainty

ID180 Easing the demonstration of safety integrated into projects using model-based system engineering and artificial intelligence

ID183 Remote imaging of the IOT integrated smartphone display for analysis of leaks in reactor pipes and vessels as an initial command for complete automatic shutdown mode in the small modular reactor plant

ID187 Advanced computer vision for automatic microstructural analysis

The on-line supplementary electronic files for this publication can be found on its individual web page at www.iaea.org/publications.

IAEA
International Atomic Energy Agency

# CONTACT IAEA PUBLISHING

Feedback on IAEA publications may be given via the on-line form available at:
www.iaea.org/publications/feedback

This form may also be used to report safety issues or environmental queries concerning IAEA publications.

Alternatively, contact IAEA Publishing:

Publishing Section
International Atomic Energy Agency
Vienna International Centre, PO Box 100, 1400 Vienna, Austria
Telephone: +43 1 2600 22529 or 22530
Email: sales.publications@iaea.org
www.iaea.org/publications

Priced and unpriced IAEA publications may be ordered directly from the IAEA.

## ORDERING LOCALLY

Priced IAEA publications may be purchased from regional distributors and from major local booksellers.

25-00423E