Light-Water Small and Medium Modular Reactor (LW-SMMR) Workshop Proceedings

Multinational Design Evaluation Programme (MDEP)

10- 11 June, 2024 - Türkiye

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Contents

List of abbreviations and acronyms

ARN	Nuclear Regulatory Authority (Argentina)
CAREM	Argentine Small Modular Reactor
CNS	Convention on Nuclear Safety
CP	Common Position
DiD	Defence in Depth
ENEA	Italian National Agency for New Technologies (Italy)
FOAK	First-of-a-kind
IAEA	International Atomic Energy Agency
JSC ASE	Engineering division of Rosatom unites (Russia)
JSC GSPI	State Specialized Design Institute (Russia)
LOCA	Loss-of-coolant Accident
LW-SMMR	Light-Water Small and Medium Modular Reactor
MASLWR	Multi-Application Small Light Water Reactor
MB	Management Board (MDEP)
MDEP	Multinational Design Evaluation Programme
MFPU	Modernized floating power unit
NDK	Nuclear Regulatory Authority (Türkiye)
NEA	Nuclear Energy Agency (OECD)
NERI	Nuclear Energy Research Initiative
NSHI	Nuclear Harmonization and Standardization Initiative
NNSA	National Nuclear Safety Administration (China)
NPIC	Nuclear Power Institute of China
OKBM	OAO I. I. Afrikantov OKB Mechanical Engineering (Russia)
PERSEO	In-Pool Energy Removal System for Emergency Operation
PSA	Probabilistic Safety Assessment

Rostechnadzor	Federal Service for Environmental, Technological and Nuclear Supervision (Russia)
SAND	Safety Assessment of Nuclear Designs Institute
SASPAM-SA	Safety Analyses of SMR with Passive Mitigation Strategies-Severe Accident
SEC NRS	Russian Scientific and Technical Centre for Nuclear Safety and Radiation Protection (Russia)
SMR	Small modular Reactor
SMMR	Small and Medium Modular Reactor
SNPP	Small Nuclear Power Plant
TENMAK	Türkiye Energy, Nuclear and Mineral Research Agency
TR	Technical Report
VDNS	Vienna Declaration on Nuclear Safety
V&V	Verification and Validation

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1. Introduction

On June 10th to 11th, 2024, the Multinational Design Evaluation Programme (MDEP) hosted a brainstorming workshop on Light-Water Small and Medium Modular Reactor (LW-SMMR), organized with engagement of international regulatory bodies and key industry stakeholders. This workshop was held at a pivotal moment in the energy sector, brought together participants from a variety of backgrounds to explore developments in SMMR technology.

MDEP's role in facilitating this workshop is essential for fostering international collaboration and harmonization in the development and deployment of Small and Medium Modular Reactor (SMMR) technology. MDEP provides a unique platform for regulatory cooperation, information exchange, and the development of technical standards and best practices. By supporting early dialogue with industry and encouraging standardization, MDEP aims to ensure that new reactor technologies meet the highest safety and environmental standards.

During the workshop, participants engaged in discussions on various aspects of SMMR safety. Especially in such important areas as: SMMR designs, prevention and mitigation of accidents, material selection, verification and validation (V&V) of the codes, probabilistic safety assessment (PSA), defence-in-depth (DiD), research needs, and recycling of SMMRs.

The success of the workshop highlights MDEP's dedication to maintaining the highest levels of safety and security in deploying nuclear technologies. The lessons learned will guide the creation of a new MDEP working group, complementing initiatives supported by the NEA to address the increasing demand for advanced nuclear technologies.

2. Opening

Mr Alexey Ferapontov, the Chair of MDEP, the Vice Chairman of Rostechnadzor[1] chaired the opening session. On behalf of MDEP Management Board (MB), he welcomed all the participants and thanked the OECD Nuclear Energy Agency (NEA) and the involved colleagues for the organizing and preparation of the workshop. He reminded that the MDEP is a unique international initiative that have been bringing together the resources and knowledge of national regulators with over 16 years of successful experiences in the cooperate review of safety of new reactor designs, such as ABWR, AP1000, APR1400, EPR, HPR1000 and VVER type technologies, including new passive safety systems, first-of- kind components, innovative materials, new fuel designs, and much more. He indicated that the energy and environmental challenges can be overcome by the use of nuclear energy in the field of new energy intensive technologies. The technology of SMMRs will play a key role in developing new spheres and extending the safe use of nuclear energy. The potential of these reactors will be useful in multiple applications, such as producing electricity and heat for smaller grids and remote areas. He stressed that the discussions of the workshop will be the basis for establishment of a new working group dedicated to the SMMR technology. This new SMMR working group under MDEP will be open for new members and will produce technical reports (TR) and common

[1] Federal Service for Environmental, Technological and Nuclear Supervision (Russia)

positions (CP), that express the regulators' consolidated position. He highlighted the importance of all the topics covered by the workshop such as SMMR designs, material selection for LW-SMMR reactor, V&V computer benchmarking for LW-SMMRs, implementation of PSA of LW-SMMR. He also mentioned the new important MDEP initiative, the Safety Assessment of Nuclear Designs (SAND) Institute, which is expected to be launched by the end of 2026 and to make a significant contribution to the development of the future MDEP activities related to capacity building of regulatory bodies.

Mr William D. Magwood thanked Mr Alexey Ferapontov for the efforts as the chairman of both SMMR workshop and MDEP and welcomed all participants in person and online. He indicated that SMMRs are one of the most important advanced technology areas being worked on to address the global need to reduce CO2 emissions. He mentioned MDEP's entire purpose is to make it possible for nuclear safety technology experts to coordinate activities to have a more global approach to these technologies, so they can be deployed around the world. The discussions of the SMMR workshop are extremely important and will contribute to the development of research programme for the future MDEP SMMR working group. Finally, he wished success for the SMMR workshop and expressed hope for more opportunities like this to continue such collaboration and engagement, particularly in the area of SMMR safety as we move forward.

Picture 1. Group Photo at Opening

3. Main sessions

The workshop consisted of discussions among representatives of industry and of national regulatory authorities for nuclear safety dedicated to: SMMR designs, Prevention and Mitigation of Accidents, Material selection for LW-SMMR, Recycling of SMMRs, V&V computer benchmarking for LW-SMMRs, Implementation of PSA of LW-SMMR, Research needs relevant to LW-SMMR and DiD principles applicability to LW-SMMR for addressing the specific safety requirements of SMMR.

3.1. Session 1: SMMR designs

Objective The objective of this session was to share various design features of different types of existing SMMR designs to support the deep discussion

for the following sessions as well as to explore interesting topics for further research by the MDEP working group.

Moderator Necati Kaya, Türkiye Nuclear Energy Inc.

Panellists Alexey Ferapontov, Rostechnadzor

Mikhail Alyokhin, Rostechnadzor

Han Ok Kang, SMART Development Group

Safety Regulation Aspects for Nuclear Power Plant with RITM-200N SMR: Alexey Ferapontov, Rostechnadzor

Mr. Alexey Ferapontov presented an overview of the RITM-200N Small Modular Reactor (SMR) project in Russia, covering its roadmap and current status, operational experience, and safety regulations for civilian vessels and other floating crafts with nuclear reactors. He discussed the advantages of the RITM-200N, key considerations for its legal regulation, areas for improvement in regulatory documents, and inter-agency working group on regulatory documentation for RITM-200N SMR. He also addressed validated and verified codes for safety justification. Mr. Ferapontov emphasized that the regulation of SMMR should take into account distinct innovative technical solutions and the detection of safety regulation deficiencies during implementation of innovative technological decisions and analysis of possible approaches to its elimination may serve as one of the goals of activities within the framework of MDEP SMMR Working Group.

Safety Regulation Aspects of Floating Power Units with the RITM-200C Reactor Unit: Mikhail Alyokhin, Rostechnadzor

Mr. Mikhail Alyokhin presented the modernized floating power unit (MFPU) with the RITM-200C, covering its technical design, main characteristics, reactor and steam turbine installations, and the electric power system of the nuclear plant. He discussed regulatory acts on ensuring nuclear radiation safety, regulation of the safety of ships and other vessels with nuclear reactors, the safety concept of MFPU, review and approval of the technical design of the MFPU with RITM-200C, implementation of the established safety requirements of the MFPU project, and operational experience in civilian vessels with nuclear reactors. He highlighted that the development of a transportable nuclear energy based on floating power units requires consolidated efforts to determine the international legal status of the floating nuclear-powered ships in the system of safety regulation in the field of nuclear energy use and maritime law.

Water Cooled K-SMR Development for Carbon Free Future: Han Ok Kang, SMART Development Group

Mr. Han Ok Kang began by outlining the current need for decarbonization and highlighting the recognized role of nuclear energy in achieving this goal. He noted that over 90 SMR designs are currently under development worldwide for various applications and these applications are being reviewed. He highlighted the Korean SMART design, which is ready for deployment and follows an ‘All-in-One’ concept, achieving significant safety enhancements through passive heat removal and advanced Loss-of-coolant Accident

(LOCA) mitigation. He presented SMART's design features, including passive systems, comprehensive technology validation, plant layout, and its position on the NEA SMR dashboard. Mr. Kang then discussed the evolution to SMART-C, a compact and customized version, followed by the i-SMR, designed for deployment scaled to demand with multiple reactors at one plant. He detailed i-SMR's primary system, safety systems, innovative technologies, reactor safety characteristics, and safety analyses. Finally, he introduced BANDI, a marine-based plant featuring a block-type reactor coolant system in which the reactor vessel and steam generator are directly connected, "nozzle-to-nozzle" without bog pipes, highlighting its key design features, safety injection, and decay heat removal systems.

Discussion

During the session, key discussions highlighted the strong international interest in SMMR due to its wide range of applications, short construction time, lower initial investment, and small emergency preparedness zone, which facilitate global deployment. Participants emphasized the importance of joint efforts within the nuclear community to demonstrate SMMR's high safety features and accelerate its design and construction. There was broad agreement that adherence to International Atomic Energy Agency (IAEA) safety principles and standards is essential for the safe design and operation of SMMR. Several SMMR designs build on reactors with long-term safe operation, enhancing confidence and providing opportunities to share practical knowledge, experience, and lessons learned for design, construction, operation, and regulation. In this context, cooperation among designers, operators, and regulators is crucial for successful SMMR deployment.

3.2. Session 2: LW-SMMR's principle for the prevention and mitigation of accidents (application of the first principle of Vienna Declaration)

Objective The objective of this session was to share the perspectives on the application of the first principle of the Vienna Declaration (Principle for the Prevention and Mitigation of Accidents) to the design of LW-SMMR, as well as to find out the interesting topics for further research by the MDEP working group.

Moderator Tania Veneau, IAEA

Panellists Iaroslav Bykh, OAO I. I. Afrikantov OKB Mechanical Engineering (OKBM)

Abel Gonzalez, Nuclear Regulatory Authority of Argentina, (ARN)

Regulatory Control Features and Principles for a Land-Based RITM-200N SNPP Project: Iaroslav Bykh, OKBM

Mr. Iaroslav Bykh presented on the first-of-a-kind (FOAK) small nuclear power plant (SNPP) project based on the RITM-200N, covering its characteristics and current status, key engineering solutions, main reactor plant equipment, safety concept, and approaches to regulatory assurance. He also discussed how international standards and

regulations were considered in the SNPP project. Mr. Bykh concluded that the review of international guidance revealed the need to update existing guides or develop new ones to ensure their applicability for the SNPP project.

Compliance with the Vienna Declaration on Nuclear Safety: Surely Mandatory for the New SMMRs: Abel Gonzalez, ARN

Mr. Abel Gonzalez recalled the background and principles of the Vienna Declaration on Nuclear Safety (VDNS) and briefed the main follow-up activities done by Argentina. He emphasized the important technical issues covered by the Vienna Declaration and shared information on the implementation of the Vienna Declaration in the design of Argentine Small Modular Reactor (CAREM), such as systematic application of the principle of DiD in the design, including the classification of structures, systems and components, the use of an integrated design that allows the exclusion of large LOCA accidents, the use of natural circulation for core cooling, the use of passive safety systems, the adoption of a 36-hours "grace period", the performance of a complete PSA for both the prevention and mitigation system, and the verification of the analysis result against a risk criterion that does not require "long-term protective measures and actions".

Discussion

During the session, participants discussed the principles of the VDNS and their application. It was noted that the IAEA safety standards fully reflect these principles in supporting the objectives of the Convention on Nuclear Safety (CNS) to prevent accidents and mitigate radiological consequences. In complement to the safety requirements on the prevention and mitigation of accidents (e.g. SSR-2/1 (Rev. 1)), the IAEA published in 2024 a new Safety Guide SSG-88 on "Design Extension Conditions and the Concept of Practical Elimination in the Design of Nuclear Power Plants".

Participants agreed that there is no need to develop new IAEA upper-level documents (SF, GSR, SSR). However, the assessment of the IAEA Guides (SSGs) in terms of their applicability for the SNPP project has shown that the existing IAEA Guides (SSGs) should be updated or new ones to be developed.

The CAREM design was presented as compliant with the Vienna Declaration principles, and the RITM-200N was described as being developed in compliance with the Russian standards, international requirements and with the best practices of using similar marine-based RITM-200S.

3.3. Session 3: Justification of the material selection for LW-SMMR reactor and primary and secondary circuits; validate the strength and lifetime of the materials used

Objective The objective of this session was to share the experiences and thoughts on the material selection for LW-SMMR reactor and primary and secondary circuits, and on the material validation, as well as to find out the interesting topics for further research by the MDEP working group.

Moderator Oya Özdere, Nuclear Regulatory Authority of Türkiye (NDK)

Panellists Evgeny Kapralov, Engineering division of Rosatom State Corporation (JSC ASE)

Justification of the material selection for LW-SMMR reactor and primary and secondary circuits; validation of strength and lifetime of the materials used: Evgeny Kapralov, JSC Atomstroyexport

Mr Evgeny Kapralov addressed key aspects of material selection for SNPP components, including material selection principles, materials approved for manufacturing nuclear power plant components in the Russian Federation, and the introduction of new materials. He described certification testing processes for new materials, covering the organization of certification commissions, test programmes and scopes, reporting on certification results, and the involvement of the nuclear regulatory authority in decisions on material use. He also discussed approaches to validating the strength and specified service life of SNPP components. Mr. Kapralov concluded that material selection is strongly influenced by component design and operating conditions, including environmental parameters and operating modes, and that component strength and reliability over the entire service life are ensured through analytical calculations and the application of minimum guaranteed material properties confirmed by operational experience and/or certification testing results.

Discussion

During the session, discussions focused on factors to consider when selecting materials, noting that materials can be categorized as either previously approved (included in established lists) or new materials requiring specific certification procedures. It was highlighted that the principles and approaches in the Russian Federation to justify the use of materials for nuclear facilities are equal to the documents of regulatory authorities of other countries with developed nuclear infrastructure.

Participants observed that most materials used for nuclear power plants are suitable for SMMRs, although exceptions may arise due to specific chemical processes. The submission of new materials for certification was described as demand-driven rather than standardized, depending on designers' current needs.

3.4. Session 4: Future perspective of recycling of SMMRs

Objective The objective of this session was to introduce the concept of recycling and to share the perspective of considering the recycling of SMMRs from the design phase, as well as to find out the interesting topics for further research by the MDEP working group.

Moderator Fulvio Mascari, Italian National Agency for New Technologies (ENEA)

Panellists Abel Gonzalez, ARN

Future Perspective of Recycling of SMMRs: Abel Gonzalez, ARN

Mr. Abel Gonzalez presented the history of recycling and practices in other industries, the nuclear recycling process, and the rationale for considering recycling in the context of SMMRs. He discussed technical challenges associated with the decommissioning and recycling of SMMRs, the proportion of components with potential for recycling, and the difficulties related to managing materials containing residual radioactivity. He highlighted key regulatory challenges for recycled goods originating from SMMRs, including complexities in controlling radioactivity in consumer products, inconsistencies across international regulations and standards, and the inappropriate use of terminology. Mr. Gonzalez also outlined suggestions for future action to support the development of an SMMR recycling policy and recommended that relevant international and intergovernmental organizations work collaboratively to address and resolve the identified issues.

Discussion

During the session, participants noted that progress in any industry, including nuclear, depends on effective recycling solutions. They emphasized that the increasing deployment of SMMRs requires a clear understanding of decommissioning processes, including regulatory frameworks, technical challenges, environmental impacts, and economic considerations. It was highlighted that implementing a comprehensive recycling cycle could enhance the commercial value of the SMMR sector, while public confidence in the feasibility of such a cycle is essential for supporting a nuclear renaissance. It was noted that by agreeing that spent nuclear fuel is an asset, we can safely store and utilize it, when necessary, rather than immediately. Finally, long-term management was recognized as involving environmental, logistical, and economic challenges that must be addressed.

3.5. Session 5: Verification and validation (V&V) computer benchmarking for LW-SMMRs

Objective The objective of this session was to share the experiences and knowledge about the verification, validation, and certification of computer codes used for SMMR design justification, as well as to explore interesting topics for further research by the MDEP working group.

Moderator Krzysztof Fornalski, Last Energy Poland

Panellists Gaojian Dang, Nuclear Power Institute of China (NPIC)

Challenges in Code Usage and Validation on China's Small Modular Reactor ACP100: Gaojian Dang: Nuclear Power Institute of China

Gaojian Dang presented the design features of ACP100, highlighting its integrated layout and passive safety systems. He provided an overview of the analytical codes applied to ACP100, discussed typical challenges associated with their use, and described current validation practices, including the subchannel thermohydraulic code CORTH, the system thermohydraulic code ARSAC, and the containment analysis code PISSA/CONT.

Planned validation activities, such as reactor commissioning tests, were also outlined. He concluded that the primary challenges in applying and validating codes for SMMRs are brought from design characteristics like integrated layouts and passive safety systems, as well as limited operational and experimental data, noting that issues related to code adaptability can be solved by performing sufficient tests.

Discussion

During the session, participants noted that most computer codes used for ACP100 can be directly adapted from those applied to existing large-pressurized water reactors, as ACP100 incorporates mature technologies from large reactor designs. However, code adaptability issues arise from ACP100's unique features, particularly affecting subchannel thermohydraulic, system thermohydraulic, and containment analysis codes. Code validation efforts face challenges related to the reactor's integrated layout, passive safety systems, and the relatively limited availability of operational and experimental data. Participants highlighted that extensive testing conducted during the ACP100 design phase has effectively supported code applicability, and that further comprehensive validation will be pursued using data obtained from reactor commissioning and operational experience.

3.6. Session 6: Implementation of probabilistic safety assessment (PSA) of LW-SMMR

Objective The objective of this session was to share the experiences and knowledge about the regulatory requirements of the PSA and the review practices of the PSA for LW-SMMR, as well as to find out the interesting topics for further research by the MDEP working group.

Moderator Mikhail Ivochkin, Russian Scientific and Technical Centre for Nuclear Safety and Radiation Protection (SEC NRS)

Panellists Victor Ibarra, ARN

Probabilistic Safety Assessment in Argentina: Victor Ibarra, ARN

Mr. Victor Ibarra presented on the Probabilistic Acceptance Criterion in Argentina and the implementation of PSA in CAREM. He discussed the general PSA situation, key challenges, including uncertainties, passive systems, and typical accident development times; and highlighted CAREM's PSA characteristics, such as its simpler design, reduced number of systems and components, elimination of typical initiating events, incorporation of passive systems, internal heat sinks within the containment, and redundant safety systems. He concluded that PSA is an essential tool in the design of new nuclear power plants, especially in the innovative ones, and for the light water reactors, the PSA tool is well known so its application is direct, and the challenges can be solved within the state of the art.

Discussion

During the session, participants discussed key points regarding PSA. The proper use of the term "probability" was highlighted as fundamental. The Argentine criterion was

explained, emphasizing that the individual risk from potential exposure should not exceed that from normal exposure. It was noted that the total risk for any member of the public around a nuclear facility must remain below 10^{-6} per year per facility. The advantages of passive safety systems were highlighted, as their failure probabilities are much lower than active systems. However, assessing these probabilities poses challenges, since certain simplifications acceptable for active systems are not valid for passive systems. A critical issue for passive safety is accurately evaluating both deterministic behaviour and system reliability.

3.7. Session 7: Research needs relevant to LW-SMMR

Objective The objective of this session was to share the experiences and knowledge about the R&D for the design of the LW-SMMR, as well as to find out the interesting topics for further research by the MDEP working group.

Moderator Uğur Çevik, Türkiye Energy, Nuclear and Mineral Research Agency (TENMAK)

Panellists Danrong Song, NPIC

Fulvio Mascari, ENEA

Progress of SMR test facility at NPIC: Danrong Song, NPIC

During the session, Mr. Danrong Song introduced the general situation (main performance parameters, function) of the SMR test facilities at NPIC, including the reactor integral hydraulic test facility, the control rod drive line test facility, the large-scale thermal hydraulic test facility, the ACP100 SMR passive safety system test facility, the supercritical water thermal hydraulic test facility, and the multi-point excitation test facility. He also provided the information on the conducted SMR tests, including the short-term performance study of the passive core cooling system, the experimental study of the long-term recirculation after water loss, the experimental study of the full-field power failure accident, the steady-state thermal-hydraulic performance test, the dynamic thermal-hydraulic characteristic test (manoeuvrability), the flow instability test, the ACP100 large-scale thermal-hydraulic test, the ACP100 control rod drive line thermal state test, the ACP100 control rod drive line seismic test.

Main R&D Needs for LW-SMR: Fulvio Mascari, ENEA

Mr. Fulvio Mascari focused on the R&D needs of the passive system for LW-SMR. He introduced the definition, categories, advantages and challenges, and applications of the passive system. He identified four main specific needs: experimental assessment database, code modelling, system reliability, system designs and engineering process. He also shared the information on the research projects relevant to the passive system, including the Multi-Application Small Light Water Reactor (MASLWR) project, the In-Pool Energy Removal System for Emergency Operation (PERSEO) project, the OSU-MASLWR natural circulation tests (TRACE code), Integral PWR design Natural Circulation Flow Stability and Thermo-hydraulic Coupling of Primary System and Containment during

Accidents project, Safety Analyses of SMR with Passive Mitigation Strategies-Severe Accident (SASPAM-SA) project.

Discussion

During the session, participants emphasized that establishing a clear map of research needs is essential for both understanding safety-related phenomena and issues associated with SMMRs and for the functions verification of the systems and components of SMMR. Research priorities related to passive safety systems were discussed in detail. It was noted that several well-developed large-scale test facilities worldwide are available to support SMMR research and development activities. Participants also highlighted a range of important experiments already conducted, including tests on passive core cooling system performance, long-term recirculation following water loss, station blackout scenarios, steady-state and dynamic thermohydraulic behaviour, as well as thermal and seismic testing of control rod drive lines.

3.8. Session 8: Defence-in-depth (DiD) principles applicability to LW-SMMR

Objective The objective of this session was to emphasize the DiD principles, and to share the considerations about the application of the Defence-in-Depth Principle in the design of the LW-SMMR, as well as to find out the interesting topics for further research by the MDEP working group.

Moderator Ali Özkara, NDK

Panellists Igor Drykin, State Specialized Design Institute, Russia (JSC GSPI)

Tania Veneau, IAEA

Realization of Defence-in-Depth Principles for Light Water Small Modular Reactors (SMMR): Igor Drykin, JSC GSPI

Mr. Igor Drykin compared the requirements of the DiD defined both in Russian and international regulations, clarified the levels of DiD, and introduced the implementation of DiD levels for the SNPPs on the basis of RITM-200N reactor, including the design requirements, the barriers on the path of radioactive substances propagation, the considered initial events, and the main measures taken to achieve the goals of each DiD level.

IAEA Activities on LW-SMRs and the Implementation of Defence in Depth principles: Tania Veneau, IAEA

Ms. Tania Veneau shared the information on the recent IAEA activities on LW-SMRs, such as the SMR Regulators' Forum, the Nuclear Harmonization and Standardization Initiative (NSHI), the publication of the Safety Report Series No. 123 on the "Applicability of IAEA Safety Standards to Non-Water Cooled Reactors and Small Modular Reactors", and the preparation of the Specific Safety Guide on the "Safety Demonstration of Innovative Technology in Nuclear Power Plants", etc. She also introduced the IAEA's focus on defence in depth based on the IAEA documents, including the Safety Reports Series

No.46 on the “Assessment of Defence in Depth for Nuclear Power Plants”, the Specific Safety Guide No.SSG-88 on the “Design Extension Conditions and the Concept of Practical Elimination in the Design of Nuclear Power Plants”, and the report of the International Nuclear Safety Advisory Group on “Application of the Principle of Defence in Depth in Nuclear Safety to Small Modular Reactors”(INSAG-28).

Discussion

During the session, participants discussed the application of the five levels of DiD to SMMRs, noting that measures and systems exist to achieve the objectives of each level. For the RITM-200N reactor, the physical barriers include the fuel matrix, fuel element cladding, reactor coolant circuit boundary, containment of the reactor facility, and containment of the reactor unit. Compliance with INSAG-10 and SSR-2/1 provisions was emphasized as important for national legislation. The IAEA’s work on SMMRs, particularly regarding the DiD concept, through safety standards development, the SMR Forum, NHSI, and other initiatives, was highlighted. Many SMMR concepts incorporate inherent characteristics and safety features at DiD levels 1–3 to limit escalation to level 4 accidents. Participants agreed that DiD principles must be implemented in SMMR design, though the methods for doing so may vary according to the unique design features of each SMMR.

3.9. Session 9: Conclusion

Objective The objective of this session was to discuss and define the key insights and challenges and recommendations from each session to support the selection of the topics for further researched by the MDEP working group in the future.

Moderator Abel Gonzalez, ARN

Panellists Presenters and moderators of all the sessions

3.9.1. The key identified challenges and recommendations

SMMR designs:

- In many countries, the regulation of SMMR mainly follows the same existing regulatory framework of the large reactors and applies the same regulatory requirements and the technical rules, and there is a lack of dedicated technical standards/rules for SMMR, which may practically limit the deployment of SMMR.
- It was recommended for MDEP to carry out further research to identify the main differences in design between SMMR and large nuclear power plants, and to identify the main issues in applying the existing standards for large reactor to SMMR, and to identify which specific technical standards should be developed for SMMR to support the establishment/optimization of the regulatory framework for SMMR in the world.
- It was pointed out that cooperation with the industry (including technology providers, owners, and operators) should be established so that real-life

difficulties encountered can be correctly identified and meaningful solutions can be provided. Such kind of cooperation at the early phases of the SMMR designs would also make important design changes to be identified earlier and implementing necessary solutions without big impacts.

- As a new type of reactor, it is important to give serious consideration to the “mitigation design features”, not only the “prevention design features "for the SMMR at the very beginning of the design to ensure the high safety feature of the SMMR and to protect the public and the environment.
- There is a crucial need to carry out research on the acceptance criteria for application of PSA in the design of SMMR and to promote the international consensus to support the SMMR design in the world.

LW-SMMR’s Principle for the Prevention and Mitigation of Accidents

(application of the First Principle of Vienna Declaration):

- The unique design and construction features of SMMRs make it challenging to apply the general principles and regulatory requirements typically used for traditional large-scale nuclear reactors.
- The developers should demonstrate that the new SMMR designs fulfil the principles of VDNS.
- It is recommended to consider the experience in design, manufacture and operation of the marine-based reactors RITM-200S, as similar to land-based RITM-200N.
- MDEP members may compare different aspects of their national safety concepts from the perspectives of prevention and mitigation.
- An interest in discussing the balance between the prevention and mitigation strategies was noted.

Justification of the material selection for LW-SMMR reactor and primary and secondary circuits; validate the strength and lifetime of the materials used:

- Reasonability of applying a graded approach in certification tests
- Differences in international legislation for land-based and floating SMMRs should be taken into account
- A kind of approved materials data bank may be developed within MDEP members
- Documents (TRs of CPs) within MDEP may be developed on material selection
- Documents (TRs of CPs) within MDEP may be developed on commendable requirements for Reports on Certification Tests

Future perspective of recycling of SMMRs:

- Defining a clear scope for international radiation protection regulations is a key challenge for regulating recycled goods from SMMRs.
- Recycling is a distinct process that follows decommissioning. SMR designers should incorporate the entire lifecycle, including recycling, during the licensing stage.
- Recycled materials can be repurposed for public use, not just returned to the nuclear industry.

- Technical Challenges: The compact and integrated design of SMMRs may necessitate specialized dismantling techniques and equipment. While the modular nature of SMMRs is advantageous during construction and operation, it can pose difficulties during disassembly.

V&V computer benchmarking for LW-SMMRs:

- The challenge for verification and validation of the SMMR codes is mainly related to the unique design features of SMMR, such as the integrated layout and passive safety system.
- The experimental tests are crucial for the validation of SMMR codes, especially for the sub-channel thermohydraulic code, the system thermohydraulic code and the containment analysis code, which are related to the main new design features of SMMR.
- Regarding the verification and validation of SMMR codes, it was strongly suggested by the participants that MDEP organize code benchmarking activities and share experimental data and analysis results to improve the efficiency of the validation and the reliability of the codes.
- It was discussed the possibility of different codes application to the same data / design solutions, e.g. for independent verification.
- It was discussed to create the common database of different codes, e.g. for commercial use and application.

Implementation of PSA of LW-SMMR:

- The estimation of doses must take into account the purpose of estimating risk.
- One of the biggest challenges are: lack of data and as the result of these difficulties which occur during fault tree analysis.
- As the project progresses, a new and more realistic version of the PSA with non-conservative approach should be developed.
- A well-documented uncertainty should be complemented with a sensitivity analysis to detect the weakness points.
- Creation a databank with the help of the states-vendors of LW-SMMR to fulfil the lack of information and proving the comprehensive probabilistic safety assessment.
- With the help of MDEP to generate consensus among regulators on common approaches in this path.
- How to summate many risks criteria in a several challenges which have not been yet touched.
- Attention should be paid to the multi-unit PSA for the SMMRs because of possible dependencies between units or modules.
- Some SMMR projects are not linked to concrete site (for example floating SMR). In light of this it should be noted the importance of external hazards for SMMR may be higher than for traditional PWR.

Research needs relevant to LW-SMMR:

- As the importance of a clear research roadmap for the deployment of SMMR was highlighted, it was strongly suggested by the participants that MDEP should

conduct research focusing on the research needs maps of SMMR, including fuels, computing codes, etc., to support the interested country to prepare their SMMR research roadmaps.

- It was also highlighted the importance of early involvement of the regulatory body in the preparation of R&D research plans to reduce the risk of violating the existing regulatory requirements for the design and deployment of new types of reactors.
- In order to reduce research cost, avoid duplications and increase the efficiency of SMMR related research, it was strongly suggested by the participants that MDEP should organize joint projects to bring together the interested countries, to use the well-developed experimental facilities and existing expertise to conduct experiments and tests and to share experimental data to support the deployment of SMMR in the interested countries.

DiD principles applicability to LW-SMMR:

- A need in modifications to traditional DiD principles depends on certain design. And there may be exceptions regarding the independence of DiD levels.
- There are radiological and other targets for each DiD levels which can be same or differ for different designs.
- Some DiD levels can be challenging to implement in comparison with nuclear power plants.
- It is necessary to be in touch with SMR Forum, NHSI to avoid significant duplication in MDEP activities.
- New and updated relevant IAEA documents (SSG-88, INSAG-28 etc.) could be subjects for discussion within MDEP, as well as benchmarking national regulations against them.
- Findings of the International Conference on small modular reactors and their application (21-25 October 2024) as well as of other events could be useful in MDEP work.
- It was strongly suggested that the DiD principles should be implemented thoroughly and carefully, especially for the first of kind SMMR to make sure the SMMR has enough safety margin for prevention and mitigation.

4. Closing remarks

Mr Abel Gonzalez, the Vice-Chair of MDEP, chaired the closing session, and invited Mr Hou Yingdong, Deputy Director General of National Nuclear Safety Administration of China (NNSA), and Mr Ibrahim Halil Dere, Vice President of NDK, to make closing remarks.

Mr Hou Yingdong thanked NEA for organizing this meeting and inviting the NNSA and appreciated the support of NDK, the participation of all the experts and the thoughtful organization of MDEP Secretary Marina Demeshko. He pointed out that China is actively promoting the construction and application of SMRs such as ACP100. The multi-purpose SMR demonstration project has started construction in Changjiang, Hainan, and in the phase of system installation and commissioning preparation. NNSA has conducted comprehensive reviews of the SMRs and other reactors using innovative technologies, accumulated review experience, and developed professional staff. NNSA has issued

guidance documents such as the Principles for Safety Review of SMRs. These documents clarify the technical and regulatory requirements for key issues. Currently, NNSA is exploring the new risk-informed safety review methodology and its application to SMRs and other innovative reactors. NNSA has a good collaboration with NEA through MDEP. In the activities of the HPR1000 Working Group and the VVER Working Group, NNSA has actively contributed to the exchange of experience and knowledge. NNSA believes that the cooperation in this LW-SMMR Working Group will also be smooth.

Mr Abel Gonzalez then made a final comment. He thanked the secretary of MDEP, all the NEA colleagues, and everyone else involved in preparation of the workshop. He also thanked all participants. He highlighted the importance of the workshop. During the sessions, participants shared ideas and suggestions about future topics for the LW-SMMR working group. He concluded by adding that working within existing groups had led to a more consistent approach to safety, ensuring that the highest safety standards are met in all MDEP countries. This is the main value of MDEP and will be a main goal of the LW-SMMR working group.

Picture 2. NDK, Rostechnadzor and NEA staff - The end of Workshop