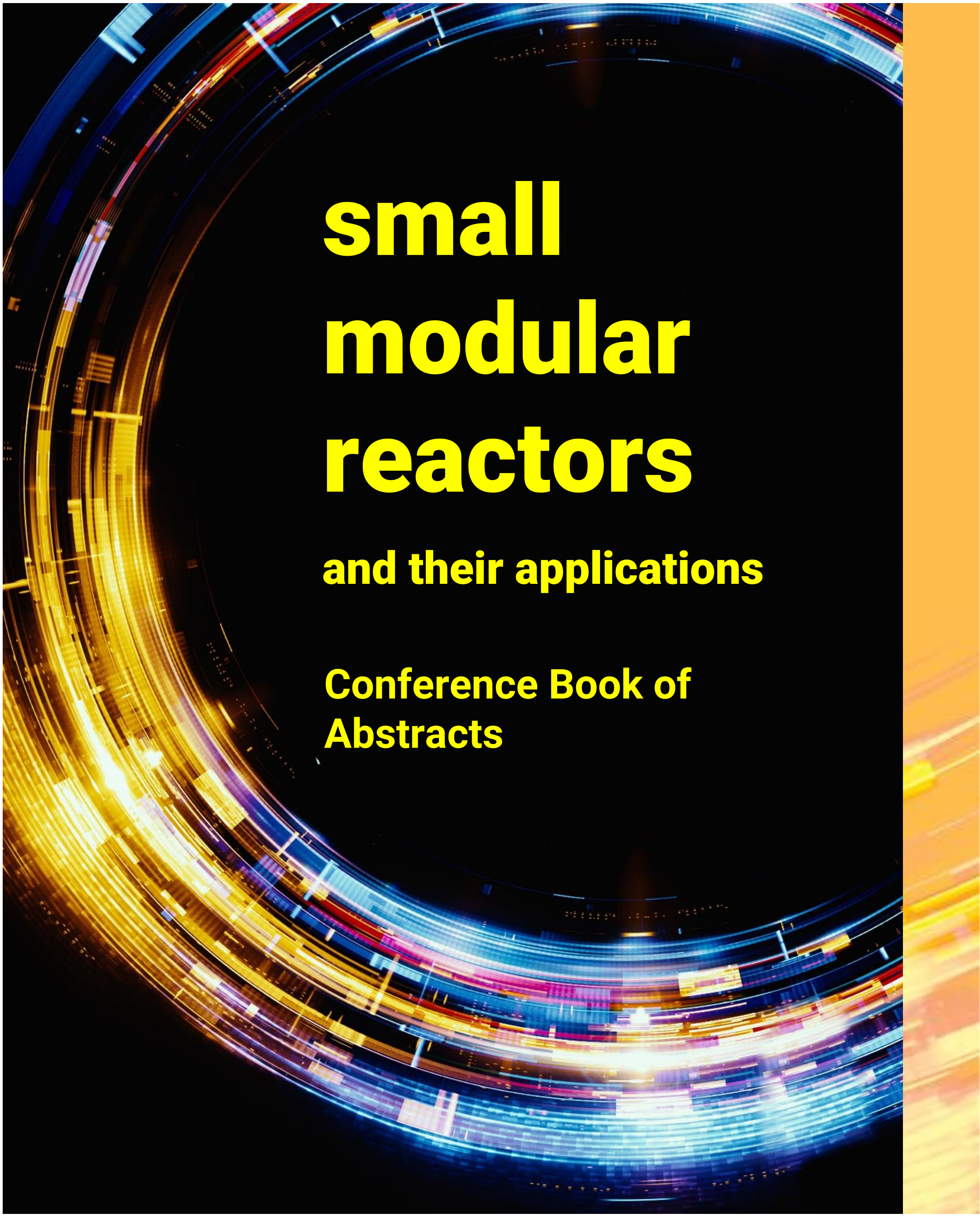
IAEA
International Atomic Energy Agency

# small modular reactors

## and their applications

## Conference Book of Abstracts



A supplement to:
The International Conference on SMRs and their Applications

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## Participating Member States and International Organizations:

Algeria, Argentina, Azerbaijan, Bangladesh , Belgium, Brazil, Bulgaria, Canada, Chile, China, Colombia, Croatia, Czechia, EC JRC, Egypt, Estonia, European Commission, Finland, France, Germany, Ghana, GIF, Hungary, IAEA, India, Indonesia, Iran, Iraq, Italy, Japan, Jordan, Kenya, Kuwait, Libya, Malaysia, Mali, Mongolia, Namibia, Netherlands, Nigeria, Norway, OECD/NEA, Pakistan, Philippines, Poland, Republic of Korea, Romania, Russian Federation, Saudi Arabia, Senegal, Slovakia, Slovenia, South Africa, Spain, Sweden, Tunisia, Türkiye, Ukraine, United Kingdom, United Republic of Tanzania, United States, Venezuela, Viet Nam, WANO, WNA, WNTI

## Scientific Programme

The purpose of this conference is to provide an international forum to take stock of the progress and discuss the opportunities, challenges and enabling conditions for the accelerated development and safe and secure deployment of SMRs among all possible stakeholders for SMRs. It is expected that this conference will help catalyse current activities in Member States and enhance prospects of safe and secure SMR deployment that will offer options for achieving clean energy transition and energy supply security in both embarking and expanding countries. Below you can find the thematic tracks for the conference.

- **Topical Group A: SMR Design, Technology and Fuel Cycle**
    - **Track 1: Design and Technology Development of SMRs** A.1

Research and development (R&D) for SMR designs of major technology lines; Concepts of modularity, design simplification and integration; Reactor physics and thermal hydraulics analyses and simulation, and experimental activities for design validation.

- **Track 2: Advanced fuels, reprocessing, waste management and decommissioning aspects for SMRs – Safety, Design and Technology** A.2

Research and development (R&D) in advanced fuel designs and technologies; fuel cycle options for SMRs; use of HALEU and higher burnups fuels; SMR designs for decommissioning; Decommissioning of non-water cooled SMRs; Waste generation and management, including transport of SMR spent fuel and waste.

- **Track 3: Engineering, Codes & Standards, Supply Chain, Operation and Maintenance of SMRs** A.3

Issues and challenges in the engineering of SMR designs; Applicability of the current codes and standards; Harmonization initiatives in C&Ss and their oversight; Procurement engineering and supply chain readiness in support of SMR deployment; Approach and preparation of operation for SMRs; simulators; construction technology, Human factor engineering for SMRs.

- **Track 4: Transportable SMRs** A.4

Microreactors and their specificities including life cycle; Floating NPPs; Transporting spent fuel from FNPP; Licensing aspects of T-SMR; Safety of transportable SMRs; SMRs for special applications.

- **Track 5: Non-Electric Applications for SMR** A.5

SMRs for cogeneration of electricity and industrial process heat; Viability of seawater desalination technology; Nuclear hydrogen production: prospects and challenges; Issues of coupling; Considerations of safety, regulation and stakeholder involvement of non-electric applications; Siting consideration; SMRs for Hybrid Energy Systems.

- **Topical Group B: Legislative and Regulatory Frameworks**
  - **Track 6: International and National Legal Frameworks and SMRs** B.6

International nuclear law instruments and their application and adequacy, challenges or gaps; Other areas of international law, such as environmental law, environmental impact assessment, law of the sea, maritime law, international waste management and transboundary movement and complementarity with nuclear law instruments; National legal frameworks including the regulatory body and its functions, facilitation of cooperation and information sharing among regulatory bodies and support organizations.

  - **Track 7: Regulatory Considerations for SMRs** B.7

Regulatory body lessons learned from assessing SMRs; Regulatory body preparation or challenges in addressing SMRs; Innovation in regulatory frameworks to address new and advanced technologies.

- **Topical Group C: Safety, Security and Safeguards**
  - **Track 8: Demonstrating SMR's Safety Case** C.8

Safety objectives and application of defence-in-depth to SMRs; Inherent and passive safety features; Safety challenges and opportunities related to design simplification, integration and modularity; Severe accidents and conditions to be practically eliminated; Internal and external hazards; Fuel and core safety; Materials and chemistry safety implications; Risk-informed approaches for SMRs; Novel deployment models and related implications on the leadership and management of safety.

  - **Track 9: Emergency Preparedness and Response for SMRs** C.9

Emergency preparedness and response (EPR) for SMRs deployed in areas with high population density; EPR for SMRs deployed in remote areas; EPR for single-module SMRs "vs." EPR for multi-module SMRs; EPR for SMRs sited near industrial sites being used for non-electric applications.

  - **Track 10: Safety, Security and Safeguards Interfaces related to SMRs** C.10

General approaches to implement safety by design, security by design and safeguards by design for SMRs; Potential challenges and synergies in consideration of 3S interfaces in the SMR design stage; Examples and practices on considering the 3S interfaces in design in an integrated manner; Technical design solutions to address 3S related challenges connected with the novelties in SMR technologies.

- **Track 11: Security of SMR: Physical Protection and Computer Security** C.11

Physical protection for SMR designs and deployment approaches; Security by design considerations; Challenges arising from SMR designs and operation that impact instrumentation and control (I&C), human factors, and computer security; Remote and autonomous operation aspects; Specific computer security challenges brought by SMRs.

- **Track 12: Safeguards for SMRs** C.12

Addressing safeguards needs for newcomer nuclear countries procuring SMRs; Addressing safeguards challenges for operations of advanced SMR technologies and fuels; Addressing safeguards challenges for non-traditional deployment (e.g., factory-fuelled TNPP/FNPP, remote microreactor fleets, multi-module operations).

- **Topical Group D: Considerations to Facilitate Deployment of SMRs**

  - **Track 13: SMRs in Energy Planning for Climate Change Mitigation** D.13

Advanced and hybrid energy systems using SMRs incorporating non-electric applications, including energy storage and hydrogen production; The role of policy makers in decision making on energy planning using SMRs.

- **Track 14: Nuclear Infrastructure and Enabling Environment for SMRs** D.14

Benefits and challenges of embarking MSs adapting their roadmaps to nuclear power with SMRs; Support of SMR technology holders in capacity building; Bilateral/multilateral regulatory and technical cooperation to facilitate SMR reviews/deployment; Human resource development; Addressing challenges in capacity/skills building in deploying SMRs in international environments; Public Engagement / stakeholder involvement in development phase).

- **Track 15: Financing, Cost & Economic Appraisals and Contracting Approaches for SMR Projects** D.15

Estimation, analyses and optimization of development costs, construction and operations expenses of SMRs; Revenue models for demonstrating business case and securing access to funding and financing; Macroeconomic impact of SMR development; Lifecycle cost of operating and decommissioning SMRs; Viable deployment and business models of SMRs; The economics of SMRs for repurposing retiring fossil-based plants.

- **Track 16: Public and Stakeholder Engagements in SMR Development and Deployment** D.16

Public engagement in the deployment of SMRs; specific challenges on SMRs; Involvement from non-nuclear stakeholders including hydrogen producers; Innovative tools and communication strategies or initiatives to facilitate SMR deployment; Engagement of investors to fund SMR projects; Engaging young generations via inter alia specific curriculum introduction in basic education.

- **Track 17: Cooperation for Harmonization and Standardization** D.17

Bilateral and multilateral cooperation on assessing SMR designs; Regulatory body approaches and experience leveraging others' regulatory reviews; Projects toward international harmonization of safety requirements; Experience/lessons learned from other industries related to international harmonization and standardization; Vendors' approaches towards standardization to enable global deployment.

**DISCLAIMER:** All abstracts in this booklet are represented as received and extracted from INDICO. Some Formatting differences may occur between abstracts.

## Topical Group A: SMR Design, Technology and Fuel Cycle

**Participating Member States and International Organizations:**

Algeria, Argentina, Bangladesh, Brazil, Canada, China, Egypt, Estonia, Finland, France, Germany, Ghana, IAEA, India, Indonesia, Iran, Italy, Kuwait, Mongolia, Netherlands, Norway, Pakistan, Poland, Republic of Korea, Romania, Russian Federation, Saudi Arabia, Spain, Sweden, Tunisia, Türkiye, Ukraine, United Kingdom, United States, Venezuela, WNTI

**Key Words:** fuel, heat, smr, temperature, core, steam, model, water, process, control

# On some safety and technology perspectives for the new nuclear reactor types

**Speaker: D. Serbanescu**

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**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 13**

## Abstract

Nuclear Power Plants (NPP) passed so far through various stages of evolution. For the Small Modular Reactors (SMR), which are part of this complex process valuable insights might be provided a triple facet perspective based on considering this type of NPP as a: I. New phase in the safety principles evolution, as for instance safety concepts or Defence in Depth II. Thermodynamic and cybernetic machine, characterized by concepts of probability, risk, entropy III. Dominant technology of the reactor core as part of a set of concurring enveloping technologies in the context of industry 4.0 phase, but with consideration of lessons learnt from natural reactors The triple facet evaluation is performed for three cases of SMR's: A. Water cooled B. Gas cooled C. Molten sault The insights could be of interest for guiding strategic research and objectives for SMR types of NPP's

# STABILITY ANALYSIS OF A SMR WITH LYAPUNOV METHODS

**Speaker: J. Riverola Gurruchaga**

Primary Author: Javier Riverola Gurruchaga [1]

*[1] ENUSA Industrias avanzadas S.A., S.M.E.*

**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 15**

**Abstract**

Light water SMRs cooled by natural circulation have intrinsic safety features that make them particularly interesting. The stability of these reactors, in which coupled neutronic, thermal and hydraulic phenomena coexist, has been satisfactorily studied for certain designs with different methods under normal and accidental conditions or after a scram. This work addresses the study of stability from an alternative point of view. Starting from the simplified differential equations of the dynamics of a reactor with the peculiarities of a light water SMR reactor cooled by natural circulation, the characteristics that determine the evolution of the system over time are studied, and the Lyapunov methods for local and global stability are applied. The NUSCALE design reactor, with data obtained or estimated from public information, is taken as a reference, but the methods are universally applicable to other SMR of the same type. As a result, local asymptotic stability has been verified by studying the responses to a step and a sinusoid of reactivity, and verifying that the eigenvalues of the equivalent reduced dynamic system are all negative. The global stability has also been tested by finding a valid Lyapunov function that involves the different state variables. Finally, it has been shown that the trajectories of the power and reactivity deviations in the phase plane converge towards the equilibrium state as a stable node. This study does not replace other existing works, but rather reinforces and aligns with its conclusions.

# Thermo-Neutronic Integrated Coupling Effects on Nuclear Reactor Core Calculations: Based on SMART Reactor

**Speaker: Y. Abbassi**

Primary Authors: Yasser Abbassi [1]; Reza Akbari; Farrokh Khoshahval; Mohammad Mirvakili; Javad Mokhtari

*[1] Reactor and Nuclear Safety Research School, Nuclear Science and Technology Research Institute, Tehran, Iran*

**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 20**

**Abstract**

New generations of nuclear reactors including Small Modular Reactors (SMRs) have received a lot of positive attention. Due to the unique features (improvement in economic and safety features) of SMRs, these reactors are under different stages of design and construction all over the world. SMART reactor as the first certified design SMR has been selected as the base case of the calculations in the present study. Different Thermo-Neutronic aspects of the SMART reactor have been investigated using an integrated coupling scheme of nuclear codes. DRAGON/DONJON codes have been used for neutronic cell and core calculation and COBRA code has been used for thermal-hydraulic calculations. Different parameters of SMART reactor core such as axial and radial PPFs, critical heat flux (CHF), minimum departure from nucleate boiling ratio (MDNBR), axial average coolant temperature in hot channel and core, and the maximum fuel temperature have been investigated using the developed coupling system. Some of the results have been checked by code-to-code verification which shows good agreement. Also, the coupling results demonstrate the non-negligible effects of the coupling in comparison to the stand-alone code modeling.

# Dynamic analysis of steam dump system of SMR

**Speaker: Y. Zhu**

Primary Author: Ye Zhu [1]

*[1] Nuclear Institute of China*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 22**

**Abstract**

The steam dump system of nuclear power plant is designed to provide an artificial secondary side load that balances the power difference between the reactor and the turbine. The steam dump system, including both process and control elements, is one of the most complicate systems in nuclear power plant, which is closely related to reactor power control, feedwater control and other process. Especially for some small modular reactors which apply once through steam generators, the characteristic is much different from the traditional NPP. In this paper, a full scope APROS model including reactor core, primary/secondary circuit and I&C system for Hainan Changjiang SMR (ACP100) is built. The large-load reduction transient such as load reduction to house load and turbine trip condition are analyzed using full-scope ACP100 APROS model. The dynamical-varying of important variables such as primary side temperature, reactor power, steam pressure etc. are recorded and studied. Optimization and improvements are made to the control logic to avoid the overpressure of the secondary circuit and the opening of main steam safety valve opening under the most unfavourable situation.

# Neutronics Design Optimization of a Sodium Cooled Micro Modular Fast Reactor Using OpenMC

**Speaker: R. Nushrat**

Primary Author: Razia Nushrat

**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 26**

**Abstract**

Very small modular nuclear reactors (vSMR), or micro-reactors, are identified as a potential means to provide reliable and cost-effective power between 1 and 10 MWe for remote installations. This paper presents a neutronic optimization study of sodium gas-cooled Micro Modular Reactor (MMR) design that has been simulated using the Monte Carlo method. As a high fidelity open source Monte Carlo code, OpenMC has been used to simulate the neutron flux distribution, power and burnup of the reactor core using ENDF-B/VII.1 data library. This Micro Modular Reactor is a 5MWe power reactor with a 20-year lifetime without refuelling, designed to operate in a fast spectrum with TRISO Fuel because TRISO particles are the leading-edge nuclear fuel form that is structurally more resistant to neutron irradiation, corrosion, oxidation and high temperature than traditional reactor fuel. TRISO fuels comprise thousands of micro-encapsulated uranium-bearing fuel kernels and are individually coated with multiple layers of pyrolytic carbon and silicon carbide that act as their own containment. This reactor model has a hexagonal unit cell with a Sodium-cooled heat pipe in the center surrounded by the TRISO particles embedded in a beryllium matrix.

# The Development status of Innovative SMR and Future Plan

**Speaker: H.g. Kim**

Primary Author: Han-gon Kim [1]

*[1] Innovative SMR Development Agency*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 27**

**Abstract**

The innovative SMR Development agency and related companies such KHNP, KAERI, KEPCO ENC, KNF are developing innovative-SMR (iSMR) since 2019. iSMR is integrated module type PWR. All the RCS components are encapsulted into small steel containment. One reactor module produces 170MWe, and one standard plant is composed of 4 reactor modules, so one standard plant produces 680MWe. There are no active component nor electricity for safety function. All engineered safety features perform their function with fully passive manner.With these feature, iSMR has very low CDF (less than 10E-9). It means that severe acciden is practically, technically eliminated. Modularization of RCS reduce overall construction period. Therefore, Nth plant of iSMR can be builted with 24 months from first concrete to operating license. iSMR has the capability to produce hydrogen and/or heat beside producing electricity. The standard design of iSMR will be completed by 2025 and the standard design approval by Korean regulatory body will be done at 2028. The first iSMR plant will be constructed early 2030s.

# Thermal-Hydraulic Calculations for the New Integral Small Modular Reactor VVER-I With Natural Circulation in Primary Circuit

**Speaker: M. Bedretdinov**

Primary Authors: Mark Bedretdinov; Oleg Stepanov

**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 36**

**Abstract**

Initial constructive development of new small modular pressurized water reactor VVER-I with natural convection in primary circuit has been started in 2022 in JSC «GIDROPRESS». The design of reactor is shown in [1]. VVER-I thermohydrodynamics calculation results which were made using one-dimensional code KORSAR/GP are presented within this work. Code KORSAR/GP [2] is widely used for NPP with VVER reactors safety analysis development. Results of provided calculations for normal operation mode of integral reactor VVER-I confirm results which were previously obtained using analytical methodology for reactor and steam generator general sizes estimation [3]. Stability of circulation and coolant parameters of primary circuit are confirmed via the calculations. During normal operation the reactor core is cooled by means of natural circulation in non-boiling mode. For basic thermal power of 250 MW and 13.4 m height of reactor vessel temperature in outlet of the core is about 310 ºC, coolant mass flow through the core equals to 820 kg/s and the temperature of overheated steam in the outlet of steam generator is about 300 ºC. It is shown that the reactor has substantial potential for thermal power increasing right up to 400 MW without significant design changes. With the exception of NuScale reactor, general sizes of which are visibly stand out of the trend maybe because of safety hull application, VVER-I rather good fits worldwide trend of such type reactors development. 1. https://www.atomic-energy.ru/news/2023/02/09/132648. 2. Yu. G. Dragunov, M.A. Bykov, V.A. Vasilenko, Yu.A. Migrov. Experience with introduction and development of the KORSAR computer code for substantiating the safety of NPSs with type VVER reactors / Thermal Engineering. 2006. 3. M.M. Bedretdinov, M.A. Bykov, O.E. Stepanov, R.M. Sledkov. Thermal-Hydraulic Calculations for the New Project of Small Modular

Reactor VVER-I, «XXXIX Siberian thermophysical workshop», 28 – 31.08.2023, Novosibirsk.

# THERMAL-HYDRAULIC MODELLING AND ANALYSIS OF A SMALL MODULAR REACTOR

**Speaker: S. El-din El-morshedy**

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**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 45**

**Abstract**

A mathematical model has been developed to simulate the thermal-hydraulic performance for a near term deployable SMR of the integral pressurized water reactor (IPWR) design under normal operation. The energy equation and the heat conduction equation are solved analytically in order to predict the coolant, clad and fuel temperature distributions. The core active length is divided into axial regions and the fuel rod is divided into radial zones, nodal calculation is performed for two types of cooling channels; the average and the hot channels. Through this model, the heat flux leading to the Departure from Nucleate Boiling (DNB) as well as the Departure from Nucleate Boiling Ratio (DNBR) predicted at each axial node for each channel using EPRI correlation. High accuracy correlations and/or models valid under the reactor operating conditions are selected to estimate the heat transfer coefficients under single-phase forced convection, subcooled boiling and bulk boiling regimes. The vapor quality and void fraction are estimated for boiling regimes as well. The model is then used to simulate the reactor performance under different core cooling flow rates ranging from 10000 to 18000 m3/h and so different subcooling margins. The developed model can be used for selecting the appropriate core flow rate and subcooling margin and performing independent thermal-hydraulic safety assessment of the reactor core under steady-state operation as well.

# EXPERIMENTAL CAPABILITY FOR INVESTIGATIONS OF THERMAL-HYDRAULIC PROCESSES AND CRITICAL HEAT FLUXES ON FULL-SCALE MODELS OF ROD ASSEMBLIES FOR SMALL MODULAR REACTORS


**Speaker: A. Gonin**

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**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 53**

## Abstract


EXPERIMENTAL CAPABILITY FOR INVESTIGATIONS OF THERMAL-HYDRAULIC PROCESSES AND CRITICAL HEAT FLUXES ON FULL-SCALE MODELS OF ROD ASSEMBLIES FOR SMALL MODULAR REACTORS J.A. KUZINA, A.I. GONIN State Scientific Center of the Russian Federation – Leypunsky Institute for Physics and Power engineering IPPE Obninsk, Russian Federation Email: aigonin@ippe.com The paper gives a brief summary of the experimental facilities available in the Leypunsky Institute for Physics and Power Engineering (IPPE) for justification of safety margins in operation of advanced small modular reactors (LWSMR). There are two experimental facilities SVD-1 and SVD-2 among other ones that are specifically focused from the view point of their unique characteristics to perform experiments to justify both new nuclear water reactor designs and to introduce changes into existing ones. Electric power up to 10 MW, which the SVD-2 has, makes it possible: - to study thermal-hydraulic parameters including critical heat fluxes in the full-scale fuel assemblies (FA) models of light water small modular reactors (LWSMR) actively developed around the world. Such works are being successfully carried out at the present time in the IPPE, including within the framework of international projects. - to carry out experiments to study critical heat fluxes and post-dryout heat transfer on full-scale height models of FA consisting of up to 25 rods for PWR and up to 37 rods for for VVER. Data obtained on such models are the most representative for the justification of reactor designs. Besides: - High pressure loop (HLP) of SVD-2 allows pressure value to achieve up to 25 Mpa that allows to carry out

thermal-hydraulic studies on FA models of generation IV reactors at near- and super-critical pressures (SCWR). - For decades the SVD-1 has been used to study thermal-hydraulic processes in fuel assemblies (FA) during core refilling under conditions of loss of coolant design accident (LOCA).

# Compact Design for CVCS heat exchangers for SMR

**Speaker: J. D. Choi**

Primary Author: Jung Dae Choi [1]

*[1] KEPCO E&C*

**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 92**

**Abstract**

The CVCS of a typical large nuclear power plant includes two shell-and-tube heat exchangers. Replacing these with a printed circuit heat exchanger (PCHE), a high-performance heat exchanger, can lead to significant space savings. Hence, this study proposes the optimized size of the PCHE for CVCS heat exchangers. The PCHE consists of a straight channel with a semi-circular cross-sectional area and performs all functions of them. Numerical solutions are obtained using the Engineering Equation Solver (EES). Since the working fluids to be heated and cooled are all single-phase water, the scope of the numerical analysis expended to the turbulent flow region. As a result of this study, it was evaluated that if PCHE is applied as a SMR CVCS heat exchanger, the space required to install the heat exchanger is less than 20% compared to the shell and tube type heat exchanger applicable to SMR while satisfying thermal hydraulic performance such as heat capacity. This PCHE is composed of a straight channel with a semi-circular cross-sectional area and performs all the functions of two existing shell and tube-type heat exchangers. Considering that volume is one of the most important indicators in SMR, this can be considered an important progress. This small-sized heat exchanger is expected to be of great help in reducing construction costs and construction periods by modularizing the entire CVCS system and allowing it to be manufactured at the factory. In addition, since the heat exchanger is manufactured through diffusion welding, stability is expected to increase.

# Development and Multipurpose Applications of Small Modular Sodium-cooled Fast Reactors in Two Component Nuclear System

**Speaker: Z. Dai**

Primary Author: Zhiwen Dai [1]

Co-Authors: Shangang Cao [2]; Zhang Donghui [2]; Zhiguang Hou [3]; Shuiwen Jiang [2]; Chengwen Xing [2]

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**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 110**

## Abstract

ABSTRACT: The Sodium-cooled Fast Reactor (SFR) has the advantages of proliferation and transmutation, coupled with the pressurized water reactors (PWR), forming the two-component nuclear energy system which holds significant importance for the sustainable development of nuclear energy under the nuclear tripling declaration at COP28. This article investigates the potential application and economic evaluation of small modular sodium-cooled fast reactors in areas such as power generation, hydrogen production, and industrial steam supply, simultaneously. Based on the current status of nuclear energy development, this study predicts and analyzes the development prospects of small sodium-cooled fast reactors within the framework of the two-component nuclear system in the future.

# Heat Transfer Simulation on HTGR Pebble Bed Using ATHLET Code

**Speaker: D. Setyawan**

Primary Author: Daddy Setyawan [1]

*[1] BAPETEN*

**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 121**

**Abstract**

High temperature reactors are helium-cooled reactors which consist largely of graphite, both fuel elements (pebbles) and the main structure material. It uses a special fuel element made of graphite in which the uranium dioxide in three-fold coated particles is homogeneously dispersed in a graphite matrix. The coatings especially the silicon carbide layer create an effective barrier against fission product diffusion. The HTGR Pebble bed, in modular design, is laid out that the maximum allowable fuel temperature of 1620 C is never exceeded in any possible accident without actuation of active components and it can solely shutdown the reactor via negative temperature feedback effects. The thermal-hydraulic fluid dynamic programme ATHLET applies the porous medium approach for flow in packed beds according to Ergun (dominance of friction). This approach uses a quasi-steady state formulation for the momentum equation while time dependent formulations are employed for mass conservation, and energy conservation for both, the solid and gaseous phase. For spatial discretisation of the conservation equations, the finite volume method is used. For material properties, gas densities, heat transfer etc. a set of constitutive equations completes the set of differential equations. Time integration in ATHLET is realised applying modified Newton Raphson method which linearizes and subsequently solves the set of equations. This study describes the modelling of a HTGR Pebble Bed using ATHLET code and outlines further HTGR-specific development perspectives of ATHLET. The objectives of this work is to simulate and compare the ATHLET results with the measurements of HTGR Pebble Bed steady state temperature distribution in the initial full-power operation. Calculation results by ATHLET for the measuring points in the reactor internals show good

agreement with the experimental values. For next study, the development of an effective thermal conductivity heat transfer model for pebbles bed Reactor on ATHLET is needed.

# CAREM - THE ARGENTINEAN SMR

**Speaker: I. De Arenaza**

Primary Author: Ignacio De Arenaza

Co-Author: Francisco Etchegaray Centeno

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 123**

**Abstract**

CAREM is a national SMR development project, based on LWR technology, coordinated by Argentina's National Atomic Energy Commission (CNEA) in collaboration with leading nuclear companies in Argentina with the purpose to develop, design and construct innovative small nuclear power plants with high level of safety and economic competitiveness. CAREM is an integral PWR type NPP, based on indirect steam cycle with features that simplify the design and support the objective of achieving a higher level of safety (integrated primary cooling system, self-pressurized, core cooling by natural circulation, in-vessel control rod drive mechanisms, passive safety systems). CAREM25 is the demonstration plant of CAREM SMR, and was developed using domestic technology. At least 70% of the components and related services for CAREM were sourced from Argentinean companies. The construction of CAREM25 has commenced, and the civil work on the reactor building is currently 85% advanced.

# Parametric survey on critical core of RFBB-SS

**Speaker: O. Sambuu**

Primary Author: Odmaa Sambuu [1]

Co-Authors: Khanh Van Hoang [2]; Obara Toru [3]; Tsendsuren Amarjargal [4]

*[1] School of Engineering and Technology, National University of Mongolia and Nuclear Research Center, National University of Mongolia; [2] Phenikaa University; [3] Tokyo Institute of Technology; [4] Nuclear Research Center, National University of Mongolia*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 130**

**Abstract**

The Breed-and-Burn reactor maximizes uranium utilization due to use of depleted or natural uranium and breeds fissile fuels while burning them. For this design, neutron economy is necessary to be high during core operation to achieve critical core. It can be accomplished by locating fuels with large neutron multiplication factors in the high neutron flux region by appropriate shuffling schemes. Our previous analysis showed that the small power (750 MWe) Rotational Fuel-Shuffling Breed-and-Burn reactor with Silicide fuel and Sodium coolant (RFBB-SS) core without considering fuel assembly (FA) duct and control rod assemblies (CRAs) can operate at critical condition and can sustain the breed-and burn operating mode. The objective of the present study is to clarify the impact of several parameters on burnup performance in practical core of RFBB-SS including FA duct and CRAs by conducting burnup analysis using Monte Carlo SERPENT code. By the analysis, the impact of the parameters on the criticality of the core in the equilibrium state was clarified. As a result, small practical RFBB-SS core loaded with fuel of 85 TD, 180 cm in height, 55 FAs per one of sixth core, and 700 days of shuffling interval can operate in critical condition.

# Status of Activities on the Project of the Land-Based Small Nuclear Power Plant on the Basis of RITM-200N Reactor Plant

**Speaker: I. Yurina**

Primary Authors: Iaroslav Bykh [1]; Dmitriy Shchekin [1]; Inna Yurina [1]

*[1] Afrikantov OKBM, JSC*

**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 136**

**Abstract**

Afrikantov OKBM JSC is a leading designer of marine reactors and has many years of experience in developing and operating marine reactors that successfully operate on in-service nuclear-powered icebreakers. Basing on the Russian nuclear shipbuilding experience a reactor plant with the maximum compact, maneuverable, highly reliable and safe at the level of the modern nuclear energy requirements was successfully developed. In February of 2020, State Corporation Rosatom decided to construct a first-of-a-kind land-based SNPP with the RITM-200N. It is designed to generate electricity up to 55 MW. The core refueling interval is at least 6 years. The service life of the permanent equipment is 60 years. Detailed designs have been developed for the reactor plant, the reactor core and the nuclear fuel handling equipment complex. In April of 2023, a nuclear plant siting license was obtained for the facility: Unit No. 1. It is planned for 2024 to obtain a construction license. The SNPP will be constructed near Ust-Kuiga village in the Republic of Sakha (Yakutia) under the severe sub-arctic climate conditions. The SNPP site will has a production zone and an additional facility zone. The small-sized NPP site layout enables a modular approach to simplifying the way of scaling up the electric output in the future. The RITM-200N design is based on engineering solutions of the RITM-200 reactor plant design that is used for nuclear-powered icebreakers. The RITM-200N compact size is achieved through placing the primary coolant system main equipment in special slots of the metal-water shield tank, which is a biological shielding element. The SNPP safety is achieved through the inherent safety properties and the

balanced use of active and passive safety systems. SNPP with RITM-200N RP meets all the requirements for power supply to remote settlements and industrial production.

# Parametric Design: Making the complex simple.

**Speaker: A. Crabb [1]**

Primary Author: Andy Crabb [2]

Co-Author: Sean Galvin [2]

*[1] TBC; [2] Atkinsrealis*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 147**

## Abstract

[Link to visual abstract][1] [1]: https://filetransferna.atkinsglobal.com/link/jPVTS9l6iFzxe5x3aO99Yy The application of parametric thinking has enabled Rolls-Royce SMR to design the latest Small Modular Reactor to encompass modularity throughout its evolution from the first principles of its bold architectural vision through to the detail of how the smallest elements are put together. Parametric modelling has given the power of great design thinking back to the designers to be able to deal with immense complexity in a coherent and coordinated way. This innovative toolset enables true three-dimensional design modelling to happen in real time while taking onboard an immeasurable number of variables. This innovative way of thinking has opened fresh new areas of computational design that can adapt to many environments ranging from shell roof structures to earthworks, to functional optimisation, to modular construction, to cost, and to schedule control. All fundamental in a production line of multiple SMR units that will benefit from design optimisation. Parametric thinking has been fundamental to the production of an efficient new form of energy production for our future energy security in the form of Rolls-Royce SMR.

# Neutronic Analysis of Westinghouse Small Modular Reactor (AP300) using OpenMC


**Speaker: W. Dridi**

Primary Author: Walid Dridi [1]

Co-Author: Sarra Moumni (research Laboratory On Energy And Matter For Nuclear Science Development, National Center For Nuclear Sciences And Technologies, Sidi Thabet Technopark) [2]

*[1] Centre National des Sciences et Technologies Nucléaires; [2] Research Laboratory on Energy and Matter for Nuclear Science Development (LR16CNSTN02), National Center for Nuclear Sciences and Technologies, Sidi Thabet Technopark*


**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 162**


**Abstract**

The study was focused on the analysis of light water Small Modular Reactor (SMR) with a square-shaped fuel element. The core design, based on the Westinghouse UO2 SMR with less than 5% enrichment was developed using the open-source Monte Carlo (OpenMC) code. Neutronics analyses of the core with UO2 fuel was achieved to characterize parameters such as the radial neutron flux profile, the maximum to average flux ratio, the reactivity coefficient and critical boron concentration at beginning of life; which confirmed good performance. The results of the simulation are compared to MCNP calculations developed by Missouri S&T.

# Computational Fluid Dynamics Approach for Optimizing Temperature and Flow Profile in a Natural Circulation Based Integrated SMR


**Speaker: A. Shafique**

Primary Author: Ammar Shafique [1]

Co-Authors: Muhammad Ishtiaq [1]; Muhammad Kashif [1]; Noman Shah [1]

*[1] Pakistan Nuclear Regulatory Authority*


**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 179**


**Abstract**

Objective of this work is to demonstrate applicability of computational fluid dynamics (CFD) techniques to perform design and safety assessment of passive primary coolant systems in integrated small modular reactors (SMRs). Passive primary coolant system, or natural circulation- based nuclear steam supply system (NSSS), is one of the most prominent features of SMR configurations where primary loop, steam generator and pressurizer are integrated into one single reactor pressure vessel (RPV). To simulate the primary coolant flow, iterative CFD analyses were performed where each analysis constitutes a certain combination of thermal gradient between the core & steam generator and their size & elevation. Given heat flux of the core, primary coolant temperature and velocity profile were computed along with heat transferred to the secondary side and corresponding temperature reduction on the primary side, in turn, improving the initially computed velocity profile for the primary coolant. The study concludes that CFD simulations offer viable solutions in terms of flow and temperature distributions, thus contributing towards safe and efficient heat transport performance of primary systems in SMRs.

# Unique nuclear heat: Blue Capsule's singular approach to design simplification and integration in small modular reactors

**Speaker: E. Hourcade [1]**

Primary Author: Edouard Hourcade [2]

Co-Authors: Mathieu Carey [2]; Alexey Lokhov [2]

*[1] TBC; [2] Blue Capsule Technology*

**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 201**

**Abstract**

With nuclear energy poised to play a more prominent role in global decarbonisation efforts, small modular reactor (SMR) innovators are seizing the opportunity that reduced use of fossil fuels implies. Currently, 10 per cent of global greenhouse gas emissions are a direct consequence of fossil fuel combustion to produce heat for industrial processes, so companies like Blue Capsule, a spin-off from France's CEA, are proposing a reactor design that maximises the production of industrial-grade heat (air at up to 700°C) for new markets; namely onsite co-location at hard-to-abate industries such as ammonia and soda ash production. For this to work, the modularity of a Blue Capsule is allied with a simplified cross-over of two mature technologies: the TRISO-based prismatic fuel from high-temperature reactors (HTRs), and the coolant of sodium-cooled fast neutron reactors. This paper explores the resulting reactor concept, identifying both the simplification and integration facets of this SMR as a unique proposition to Europe's SMR ecosystem. The paper finds that Blue Capsule's design can address well-known difficulties associated with nuclear technologies: (i) safety, regulatory and physical issues (i.e. cold source availability); (ii) the competitiveness of nuclear heat compared with fossil fuel heat, and; (iii) low maximum temperatures for nuclear reactors available on the western market.

# THE OTRERA SODIUM FAST REACTOR PROJECT: FROM PRELIMINARY TO CONCEPTUAL DESIGN PHASE

**Speaker: F. Varaine**

Primary Author: Frederic Varaine

Co-Author: Remy Dupraz

**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 210**

**Abstract**

The purpose of this paper is to introduce the technical and economic performances of the AMR OTRERA developed in France and the development roadmap. OTRERA is an innovative AMR (Advanced Modular Reactor) reactor that brings real breakthroughs compared to the competition, giving it a unique market positioning and higher than average profitability. Its unit capacity of 300 MWth enables it to meet local needs, whether those of conurbations or industrial sites. The OTRERA reactor is a fast-spectrum, 4th-generation reactor that uses spent fuel from conventional reactors soil in spend fuel storage pools, and recycles it for its own operation. The reactor's long operating autonomy, of the order of 10 years, ensures stable, reliable electricity production. OTRERA's cogeneration heat offers a unique business model that makes it highly profitablé by offering a wide range of industrial purposes. To meet the challenge of rapid deployment the OTRERA reactor relies on: • Sodium Fast Reactor technology, which is the most mature of the 4th generation technologies. • Its own technological advances, based on the experience of its founders and the technological building blocks developed during the ASTRID program. • On the strength of this technological lead, we are proposing to commission a first series reactor by 2032 and then rapidly deploy more than hundred reactors in around twenty years.

# Thorizon's cartridge core molten salt reactor

**Speaker: S. De Groot**

Primary Author: Sander De Groot [1]

*[1] Thorizon*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 237**

**Abstract**

Low pressure operation, and elimination of potential escalation by laws of physics, combined with large fuel flexibility, neutron spectrum flexibility, and convenient connection to reprocessing and subsequent fuel production, make molten salt technology the superior basis for next generation nuclear power reactors. The key challenge of molten salt reactors relates to the structural materials in contact with the primary salt, which are exposed to high temperatures, radiation damage and chemical interaction. Instead of trying to find and qualify materials that can withstand these conditions for the typical lifetime of a nuclear plant, Thorizon has mitigated material degradation issues by integrating a replacement strategy in the reactor design. The patented Thorizon reactor core concept is modular, consisting of a number of so-called cartridges which can be replaced and maintain nuclear containment at all times. The benefits of this approach, in terms of safety, practical and economic feasibility, qualification, licensing, time to build and the convenient connection to reprocessing facilities will be explained. In addition, a cartridge based experimental validation and qualification strategy will be elaborated, enabling an ambitious timeline to realization of a 250 MWth Thorizon first of a kind.

# Using open SMR datasets E-SMR and LDR lite for research and training purposes

**Speaker: V. Tulkki**

Primary Author: Ville Tulkki [1]

Co-Authors: Marton Szogradi [1]; Fares Alblouwy [1]; Rebekka Komu [1]; Riku Tuominen [1]

*[1] VTT Technical Research Centre of Finland ltd*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 274**

**Abstract**

Many Small Modular Reactor (SMR) designs rely on innovative safety features, which may differ from those of currently operating in conventional nuclear power plants. Access to simulation models of such nuclear units allows interested parties to build expertise prior to licensing processes. Two SMR datasets, E-SMR and LDR lite, have been recently published, and this paper presents examples of design basis accident scenario simulations on models made with those datasets performed at VTT. The E-SMR dataset was created in EURATOM-funded ELSMOR (towards European Licensing of Small Modular Reactors) project, to demonstrate a safety philosophy similar to other PWR-type SMRs. The dataset was published under CC-BY-NC 4.0 license and has been used to perform design basis accident scenario benchmarks. The LDR lite dataset is a public version of the Low-temperature District heating Reactor (LDR-50), intended for academic research. Designed by VTT, LDR-50 is suitable for district heating and other low-temperature applications, which influenced the design of the reactor to include different innovative passive safety systems designs and approaches.

# SMR Deployment: FOAK (First-of-a-Kind) Risks & Risk Mitigation Strategies

**Speaker: I. Ali**

Primary Author: Irfan Ali [1]

*[1] ARC Clean Technology, Inc.*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 315**

**Abstract**

To realize the full potential of SMR technology towards a long-term, global future based on clean energy, the nuclear industry has to successfully surmount a number of key challenges. While the new generation of nuclear technology, in the form of numerous SMR options, holds tremendous promise, the successful commercialization of these new reactors has to address several critical elements. Chief among these is the development and construction of First-of-a-Kind (FOAK) projects. While any FOAK project, in the energy industry or otherwise, is challenging in its own right, nuclear FOAK projects carry a distinctive level of complexity due to a unique combination of technical, financial and regulatory burdens. Even in instances where specific SMR designs are based on sound technology, with promising results in laboratory environments, the process of converting this sound technology to successful commercial product is long and arduous. This paper will undertake a comprehensive assessment of the risks associated with SMR FOAK projects and propose plausible mitigation strategies for these risks.

# Italy's Journey into Small Modular Reactors: Research, Safety Assessment, Testing, and Future Prospects

**Speaker: M. Caramello**

Primary Authors: Marco Caramello [1]; Michele Frignani [2]; Walter Ambrosini [3]; Gianfranco Caruso [4]; Marco Ricotti [5]; Fulvio Mascari [6]; Federico Rocchi [6]; Calogera Lombardo [6]; Massimiliano Polidori [6]; Giacomo Grasso (italian National Agency For New Technology, Energy And Sustainable Economic Development) [7]; Francesco Lodi [6]; Mariano Tarantino [6]; Alessandro Petruzzi [8]; Andrea Achilli [9]; Roberta Ferri [9]; Carlo Randaccio [9]; Marco Tudor Cauzzi [9]; Andrea Bersano [9]

*[1] Ansaldo Nucleare; [2] Ansaldo Nucleare S.p.A.; [3] Pisa University; [4] Sapienza Università di Roma; [5] Politecnico di Milano; [6] ENEA; [7] Italian National Agency for New Technology, Energy and Sustainable Economic Development (ENEA); [8] NINE; [9] SIET*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 317**

**Abstract**

Italy's interest and involvement in Small Modular Reactors (SMR) and Advanced Modular Reactors (AMR) technologies dates back to almost two decades ago and had a notable surge in recent years. As a nation investigating the possibility of restarting a nuclear program, Italy has recognized the potential of innovative nuclear technologies to contribute to its energy security and sustainability goals, and to diversify its portfolio of low carbon resources. This article explores Italy's engagement in SMRs and AMRs, spanning from design activities, numerical studies, safety assessment and testing endeavors. In particular, recent efforts within the context of thermal-hydraulics, neutronics, fuel performance, safety and licensing and material testing are reported. Worth mentioning, the Italian nuclear sector leverages a collaborative effort between academic institutions, research organizations, and industry stakeholders. By providing a comprehensive overview of Italy's involvement in forthcoming nuclear technologies, this article aims at contributing to the global discourse on nuclear energy innovation and its role in addressing contemporary energy challenges.

# Experiment and Modeling Efforts to Support Development and Deployment of Advanced Energy Systems

**Speaker: P. Sabharwall**

Primary Author: Piyush Sabharwall [1]

Co-Authors: Mauricio Tano [1]; Youssef Ballout [1]

*[1] Idaho National Laboratory*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 318**

**Abstract**

Advanced energy systems are the next generation of energy systems with self-control and monitoring attributes along with passive safety measures that are being designed and developed across the globe. Self-control of primary processes refers to the reactors inherent safety, whereas passive safety features are vital in operation when strong deviation of normal process behavior occurs. For supporting the verification and validation for these novel systems there are modeling and experimental efforts being supported under various Department of Energy programs. Both these efforts need to synergize to support a successful accelerated deployment. This article provides an overview on the test beds being designed and developed along with the modeling efforts in the Multiphysics Object-Oriented Simulation Environment (MOOSE) that supports multiphysics modeling and simulations, i.e., neutronics, thermal-hydraulics, thermomechanics, and thermochemistry, of advanced nuclear reactors for engineering design, safety studies, licensing, and operational support. The experiments being designed and carried out will support technology maturation, and reduce uncertainty and risk associated with the design, operation, and deployment of next generation energy systems, such as small modular reactors and microreactors.

# Modeling of Proposed Passive Heat Pipe Loops Cooling System

**Speaker: M.s. Abdelaziz**

Primary Author: Mohamed Salem [1]

*[1] EAEA*

**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 319**

**Abstract**

Abstract Heat-pipes are passive heat transfer devices, which have very long lives when properly designed and fabricated. Fuel pool Heat should be removed to keep fuel temperature within safe limit. A gravity assisted two-phase closed heat-pipe loop (GTPCHL) as a passive cooling system could be used to remove this heat. This paper proposes a completely passive cooling system using loop heat-pipe for cooling and dissipation the heat. The design is focus on heat removal from the pool of the small reactor to be in safe mode. The model considers natural convection by air for the condenser part of the heat-pipe loop to confine the heat. A numerical simulation using special design of (GTPCHL) were used to investigate the thermal performance. The effects of evaporator and condenser configuration, atmospheric air temperature, and heat load were analyzed. Demineralized water was used as the working fluid. The atmospheric air was circulated around the condenser as a heat-sink. The results show that the best thermal performance was obtained at a low atmospheric air temperature, biggest evaporator and condenser surface area, and a high evaporator heat load. The simulation model showed a pattern that can be used to predict the heat transfer phenomena of (GTPCHL) with varying inputs. A theoretical network model has been proposed to predict the transient response of (GTPCHL) at different heat loads (100, 200, 300, 400 and 500 kW). From this model wall and fluid temperatures, heat transfer coefficients, time constants, and other thermal characteristics have been estimated. The transient response of (GTPCHL) was found to depend mainly on the average evaporator thermal resistance. Increasing the heat loads causes a reduction in thermal resistance and in time constants, which leads to better performance of the heat pipe. The

evaporator and condenser heat transfer coefficients were found to increase with increasing power.

# Core Geometry and Reflector Optimization of 10 MWt Micro-PeLUIt Pebble Bed HTGR

**Speaker: F. Miftasani**

Primary Authors: Dwi Irwanto [1]; Fitria Miftasani (national Research And Innovation Agency, Indonesia) [2]; Topan Setiadipura (national Research And Innovation Agency, Indonesia) [2]; Zaki Suud [1]; Nuri Trianti (national Research And Innovation Agency, Indonesia) [2]; Nina Widiawati (national Research And Innovation Agency, Indonesia) [2]; Cici Wulandari [1]

*[1] Institut Teknologi Bandung; [2] National Research and Innovation Agency (BRIN), Indonesia*

**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 321**

**Abstract**

Previous research has explored the effects of reducing the size of nuclear reactor cores to identify smaller, optimal dimensions for applications in remote Indonesian locations. This investigation aimed to reduce the core dimensions while maintaining the height-to-diameter ratio (H/D) at 1.1, following the HTR-10 model. The previous findings indicated that, with a minimum burnup target of 60 MWD/kg-HM, the optimized reactor volume is 4.4 $m^3$, featuring a diameter of 172 cm and a height of 189.2 cm. Lowering the burnup target revealed five alternative geometric configurations for a downsized Peluit 10 MWt reactor. This study delves into the impact of reflector size modifications on these five reactor geometry options, employing the Pebble Bed Reactor Neutron Diffusion (PEBBED) Code, a computational tool designed for analyzing High-Temperature Gas-cooled Reactor (HTGR) physics, specifically Pebble Bed Reactors. The analysis encompasses neutronic parameters such as total fuel flow, burnup, power peaking factors, and power density distribution, which are critical for understanding the reactor's performance and safety. Furthermore, the study examines thermal-hydraulics and safety parameters, including steady-state and transient fuel temperatures, focusing on scenarios involving Depressurized Loss of Forced Cooling (DLOFC) accidents. This comprehensive analysis aims to enhance the design and safety features of compact nuclear reactors suitable for isolated areas, contributing to developing more accessible and safe nuclear energy solutions. Keywords: HTGR, PEBBED, PeLUIt-10, TRISO, Pebble bed

# HEXANA: a sodium advanced modular reactor for sustainable industrial decarbonization

**Speaker: P. Gauthé**

Primary Author: Jean-baptiste Droin

Co-Authors: Paul Gauthé; Sylvain Nizou

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 325**

**Abstract**

HEXANA is a French start-up committed to the design and development of an innovative small modular sodium fast reactor. Its objective is to deal with the key challenges of the energy transition that are still poorly addressed today, mainly through the decarbonization of the hard to abate energy intensive industries and the need for flexible power sources in addition to renewable energies. The Sodium Reactor technology has been chosen because of its favorable technical specifications for end-users (high temperature, good electrical efficiency…), but above all because of the high technological readiness level and the high level of credibility that it offers and which results in a quite short time-to-deployment compared to other systems. The proof of concept is already demonstrated at an industrial scale, but HEXANA brings several innovations in terms of architecture and of use of energy. The power of this reactor is 400 MWth for each module, and HEXANA provides two twinned reactors associated with thermal storage (molten salt) offering flexible power delivery in response to the needs of its customers for industrial process needs. HEXANA integrates design options offering high guarantees from the point of view of safety, relying in particular on passive safety devices. The design of the nuclear island is made modular, so that factory-building and transport on-site by sea or by river is possible, which is a key driver for competitiveness. HEXANA is primarily targeting the combined production of heat and electricity, bases for the production of hydrogen or synthetic fuels. The level of heat (up to 500°C) actually gives access to all the amenities needed to defossilize our economy: steam, hydrogen, $CO_2$, synthetic fuels, green steel, chemical molecules, etc. All these features confirm that the solution proposed by HEXANA is relevant to decarbonize industrial hubs in a robust and credible way.

# SMR Current Status: Development Needs and Global Perspectives

**Speaker: P. Sabharwall [1]**

Primary Author: Palash Kumar Bhowmik [2]

Co-Authors: Piyush Sabharwall [3]; George Griffith; Youssef Ballout [3]

*[1] TBC; [2] Staff Scientist, Idaho National Laboratory; [3] Idaho National Laboratory*

**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 328**

**Abstract**

Defined as nuclear reactors with a power output up to 300 megawatts electrical (MWe) by the International Atomic Energy Agency (IAEA) and targeted for multipurpose applications, small modular reactors (SMRs) have been recognized as a very promising, clean, affordable, and sustainable energy source by many countries. At present, more than 80 SMRs are under design, development, demonstration, deployment, and beyond (4D+) phases worldwide. This study focuses on the current world status of SMRs and focuses on the necessary developments to accelerate the process of adopting SMRs as a major energy source globally. SMRs are not a new concept, but they do represent a new vision for older concepts if the challenges inherent within them are mitigated with strategic and realistic solution approaches. The major challenges for SMRs 4D+ are: (a) qualifying the advanced fuel-to-reactor design; (b) supporting rapid scaled/prototypic experimentations; (c) maintaining local and global codes and standards, supply chain issues, and regulations; (d) ensuring innovative but effective strategic and legislative commitments for the cradle-to-grave nuclear fuel cycle and transportation, and (f) mitigating financial and environmental risks. These challenges can be mitigated with a synergistic solution approach among the various stakeholders: industry, academia, research, government, and international entities.

# SVBR-100 PROJECT: MAIN FEATURES AND CURRENT STATE

**Speaker: A. Dedul**

Primary Author: Alexander Dedul [1]

Co-Authors: Oleg Komlev [1]; Alexaey Kondaurov [1]; Alexander Martynenko [1]; Vladimir Petrochenko [2]

*[1] JSC AKME-engineering; [2] Russian Federation*

**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 329**

**Abstract**

The SVBR-100 reactor facility with a fast neutron reactor, an integral layout of the primary circuit and a lead-bismuth coolant in the primary circuit is being developed as one of the main components of serial NPPs of modular design with an average power from 100 to 600 MW (e). The main design provisions of the SVBR-100 reactor facility,presented in the paper,are aimed at simplifying the design of reactor facility equipment and systems, using the inherent safety characteristics and passive systems to increase the resistance of the reactor facility to potential hazards. Due to the developed properties of internal self-protection, the number and complexity of safety systems has been significantly reduced in comparison with traditional reactor facilities. Key technical solutions used in reactor plant designs are based on mastered production materials and technologies. The most important technical characteristics of the reactor facility are presented in Table below. Main technical characteristics of reactor facility SVBR-100 Characteristic Value Thermal power, MW 280 Pressure of generated saturated steam, MPa 7.0 Steam capacity, t/h 580 Coolant temperature at core inlets/outlets, °C 340/490 Fuel OU2 Average fuel enrichment for U-235, % 16.7 Maximum fuel enrichment for U-235, % less than 20 Core campaign, thousand effective hours 50 Time interval between refueling, years 6-7 Reactor dimensions: diameter/height, m 4.53/7.86 A significant amount of R&D has been carried out to substantiate the technical design of the reactor facility. The most important results and the main directions of activities for completing the justifications are presented in the paper. In-depth technical and

economic researches carried out on the basis of design documents demonstrate the competitiveness of the product being created.

# Low Energy Linear Accelerator-Driven Subcritical Molten Salt Reactor to Produce Clean CO2-Free Energy with Stirling Cycle

**Speaker: E. Greaves**

Primary Authors: Laszlo Sajo-bohus [1]; Eduardo Greaves [1]

*[1] Universidad Simon Bolivar*

**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 332**

## Abstract

Abstract A radiotherapy electron accelerator (LINAC) operating on the usual bremsstrahlung producing energetic photons (5.5 – 25 MeV) provides demonstrated [ , ] neutron production when operating in the Giant Dipole Resonance (GDR) region where most medical linacs are actively operated. It is employed with effectiveness to induce neutrons via the reactions (γ , n), (γ , fis) and (e , e'n) in the accelerator's W-target and thereby controlling fission energy production in a subcritical Accelerator Driven Molten Salt Reactor operating in a thermal neutron regime. FliBe molten salt with dissolved 0.25 mol% fissile 335U, 233U or 239Pu provide the reaction media with power totally controlled by the external electron accelerator neutron source. The thermal energy is used to drive a Stirling cycle motor to directly provide electric power production. 1 R. R. Martín-Landrove, E. D. Greaves, L. Sajo-Bohus, et al. (2015) GDR in Radiotherapy Treatment Fields with 18 MV Accelerators. pp 369-376 In PROCEEDINGS OF THE 14th INTERNATIONAL CONFERENCE ON NUCLEAR REACTION MECHANISMS Varenna, June 15 – 19, 2015, 2 L. Sajo-Bohus and E. D. Greaves. (2016) Low energy linear accelerator-driven subcritical assembly. In Chap.15 of Molten Salt Reactors and Thorium Energy. Ed. Thomas Dolan, Pub. Elsevier.

# Tube inlet orifice design of a once-through steam generator considering operation strategies

**Speaker: H. S. Han**

Primary Author: Hun Sik Han [1]

Co-Authors: Young In Kim [1]; Youngmin Bae [1]; Seungyeob Ryu [1]

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**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 336**

**Abstract**

A numerical study is conducted for a thermal-hydraulic performance analysis and secondary side screw-type tube inlet orifice design of a once-through steam generator (OTSG). Various tube-plugging conditions and power levels are considered, and the secondary coolant inlet temperature is adjusted to maintain a constant level of thermal power. Comprehensive numerical solutions are acquired to evaluate the thermal-hydraulic performance and minimum orifice length of the OTSG under various operating conditions. The results obtained show that constant thermal power can be maintained by properly adjusting the secondary coolant inlet temperature with variation of the steam outlet superheat degree and secondary coolant pressure drop when the OTSG operates at a high power level. The lowest power level results in the highest minimum orifice length, and non-plugged condition practically limits the orifice length criterion. This OTSG performance and orifice length are compared with those when the secondary coolant flow rate or secondary coolant outlet pressure is controlled for constant thermal power operation. The secondary coolant outlet pressure control operation with the highest secondary coolant pressure provides the smallest tube inlet orifice size and it accordingly results in the lowest hydraulic pumping power through the orifice. The orifice size is almost unchanged with respect to the constant thermal power operation strategy when the secondary coolant control parameter is the inlet temperature or flow rate because both schemes provide nearly identical secondary coolant pressures.

# Novel design features of proposed light-water SMRs — a Swedish perspective

**Speaker: J. Eriksson**

Primary Author: Johan Eriksson [1]

Co-Author: Teodora Retegan Vollmer [1]

*[1] Nuclear Chemistry, Chalmers University of Technology*

**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 343**

**Abstract**

Deployment of land-based light-water SMRs is one of the options considered for adding new nuclear capacity in Sweden. In comparison with the currently and previously operating Swedish reactors, the proposed SMR designs entail a number of novel features. In this ongoing work such novelties are being identified and the need for further research is evaluated. A shortlist of five SMRs, one BWR and four PWRs, that are deemed the most probable to be constructed in Sweden in the relatively near future has been compiled. Notable technical differences compared with the Swedish reactor fleet include: • Novel passive approaches to safety • Novel containment designs • Integral PWR designs • Boron-free PWR coolant • Increased load-following capability Some of the features have not been widely tested in commercial reactors. There is thus a need to verify the adequate functionality of these novelties, both experimentally and theoretically. Other of the features are already utilised in reactors outside Sweden. The need to investigate them from a technical perspective is thus not as high as for the untested ones. However, there might still be regulatory aspects to consider before being able to implement them in Sweden. This poster will present critical investigation needs related to the noveltiesto enable licensing, construction, and operation of the shortlisted SMRs.

# Experimental Investigation and Modeling of Passive DHRS with Plate-Type Compact Steam Generator


**Speaker: A. Missaglia**

Primary Author: Andrea Missaglia [1]

Co-Authors: Alessandro Alemberti [2]; Andrea Bersano; Marco Caramello [2]; Calogera Lombardo [3]; Stefano Lorenzi [1]; Marco Ricotti [1]

*[1] Politecnico di Milano; [2] Ansaldo Nucleare; [3] ENEA*


**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 346**


**Abstract**

Within the EU-funded ELSMOR (Towards European Licencing of Small Modular Reactors) project, an experimental facility has been built at SIET (Piacenza, Italy) to test a passive Decay Heat Removal System (DHRS). Based on natural circulation, the main peculiarity is the adoption of a plate-type compact steam generator as heat source, whereas the heat sink is an in-pool condenser. An experimental campaign was conducted to investigate the effect of various parameters on the DHRS behavior, such as the secondary side filling ratio, the primary system temperature, the pool level, etc. The present activity simulated the ELSMOR test 00100_C where the reduction of the secondary side filling ratio is enough to trigger oscillations observed experimentally on the secondary side flow rate. Adopting the RELAP5 code, the simulations predicted the experimental data both qualitatively and quantitatively, promisingly encompassing the primary physical phenomena essential for the system's performance. Few discrepancies were noted in predicting the secondary side pressure, primary side compact steam generator outlet temperature and secondary side flow rate, highlighting the need for further code development and validation to support the adoption of compact heat transfer devices on safety related systems. In the context of advancing Small Modular Reactor (SMR) technologies, this paper contributes valuable insights into the validation of passive DHRS, addressing critical challenges and paving the way for enhanced safety and efficiency in future SMR deployments.

# Current status of SMRs development

**Speaker: I. Pioro**

Primary Author: Igor Pioro [1]

Co-Author: Romney Duffey

*[1] University of Ontario Institute of Technology*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 350**

**Abstract**

Small Modular Reactors (SMRs) (installed capacity ≤300 MWel) are today's a very "hot" topic in nuclear engineering / nuclear-power industry worldwide. In general, there are about 108 concepts / designs of SMRs, which can be classified as: 1) Water-cooled SMRs (land based) – 33; 2) Water-cooled SMRs (marine based) – 7; 3) High-temperature gas-cooled SMRs – 21; 4) Fast-neutron-spectrum SMRs – 26; 5) Molten-salt SMRs – 17; and 6) Other SMRs – 4. From all these 108 SMRs only two KLT-40S reactors (PWRs) (Russia) have been constructed, installed on a barge, and put into operation in December of 2019 in the port of Pevek, Chukotka and RITM-200M was designed and manufactured; also, two High Temperature Reactors Pebble-bed Module (HTRs-PM) SMRs cooled with helium were constructed and put into operation in March of 2023 in China. Based on these two examples of operating SMRs the following conclusions can be made: SMRs usually require a higher level of fuel enrichment up to <20% to operate with a smaller amount of fuel and to have longer terms between refueling and, usually, lower NPP thermal efficiencies compared to those of large nuclear-power reactors NPPs of the same type. Also, some other issues have to be resolved before a widespread implementation of SMRs, which include: Legal frameworks for widespread enriched-fuel utilization and its interstate transportation; elimination of potential for plutonium production; sabotage and terrorist-attacks prevention; accounting and remote monitoring of nuclear materials; assured cooling of spent nuclear fuel (SNF) during transportation; and equipment operating without maintenance for a time commensurate with core lifetime. However, in spite of all these difficulties in SMR development, they will undoubtedly have their unique "niche" applications of being implemented in remote areas, small electrical grids, military facilities, and as floating NPPs.

# Performance Optimization Analysis of PeLUIt-40 using HTGR Code Package (HCP)

**Speaker: N. Trianti**

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Co-Authors: Dwi Irwanto [2]; Fitria Miftasani (national Research And Innovation Agency, Indonesia) [3]; Topan Setiadipura [4]; Zaki Suud [2]; Nina Widiawati (national Research And Innovation Agency, Indonesia) [3]; Cici Wulandari [2]

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**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 351**

## Abstract

The PeLUIt-40 (*Pembangkit Listrik dan Uap untuk Industri*) reactor, a pebble-bed High-Temperature Gas-Cooled Reactor (HTGR) with a power of 40 MWt designed for electricity and co-generation applications, holds promise as a solution for clean energy. A thorough examination of neutronic and thermal-hydraulic aspects is essential to assess the resilience of the PeLUIt-40 design and ensure compliance with safety standards. This study focuses on evaluating the reactor's resilience and safety through comprehensive analyses of neutronic and thermal-hydraulic aspects. Leveraging the HTGR Code Package (HCP), we aim to optimize its operational dynamics, enhancing efficiency and sustainability. The research integrates various simulations enabled by the HCP to provide detailed insights into PeLUIt-40 behavior. Neutronics simulations offer an understanding of neutron flux distributions, criticality, fuel depletion, guiding control strategies, and fuel management. Thermal-hydraulic analyses elucidate coolant flow characteristics and temperature profiles critical for maintaining safety margins. Safety analyses assess accident scenarios, i.e., Depressurized Loss of Forced Cooling (DLOFC), ensuring the reactor's resilience against unforeseen contingencies. Integration of these analyses aims to enhance reactor performance and highlight PeLUIt-40 potential for

electricity and co-generation applications. This research will contribute to ongoing discussions on advanced reactor technologies and inform future HTGR design and operation advancements.

# Overview of Modified Design Features of SMART-C


**Speaker: M. Young Park**

Primary Author: Minyoung Park

Co-Author: Sung Won Lim


**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 352**


**Abstract**

Small Modular Reactor (SMR) has gained global attention owing to its numerous advantages. SMART (System-integrated Modular Advanced ReacTor) is one of the most verified SMR designs which has obtained Standard Design Approval (SDA). Recently, a variation of SMART100 (System-integrated Modular Advanced ReacTor100), has been suggested. The newly proposed reactor, SMART-C is an advanced concept of the SMART100 in terms of portability and economic viability. The portability of the SMR is vital for the application of the SMR in rural areas and various industries including oil sand industries. In order to achieve these aspects, design modifications have been conducted on SMART100. The design modifications include; weight reduction of the reactor pressure vessel and simplification of the safety systems. In this study, the modified design features of SMART-C are summarized and presented. Furthermore, the associated issues are addressed.

# Delivering on the Promise of Small Modular Reactors

**Speaker: R. Baranwal**

Primary Authors: Rita Baranwal [1]; Vincent Thomas [1]

*[1] Westinghouse Electric*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 370**

**Abstract**

The Westinghouse AP300™ SMR is the Only SMR based on Licensed, Operating & Advanced Reactor Technology. It is the most advanced, proven and readily deployable SMR solution. Westinghouse proudly brings our experience developing and implementing new nuclear technologies, from the introduction of the U.S. Navy's first submarine nuclear reactor (the USS Nautilus) and the world's first commercial pressurized water reactor in 1957 (Shippingport), to today having Westinghouse technology as the basis for approximately 50% of the world's operating nuclear plants. The Westinghouse Gen III+ AP1000® reactor is currently proving itself every day around the globe. Currently, four units utilizing AP1000 technology are operating in China, setting performance records. Eight more are under construction in China and one AP1000 reactor is operating at Plant Vogtle in Georgia while a second nears commercial operation. The AP300 SMR leverages that operating experience, as well as tens of millions of hours on AP1000 reactor development. The AP300 SMR has the benefits of record-setting Westinghouse AP1000 PWR technology in a smaller power output to augment the backbone of any community's energy system. The AP300 SMR R&D program draws on the lessons learned from the AP1000 deployments and furthers concepts of design simplification and modularity.

# Heat Distribution Results from Experiments Using Array of 5 Sodium Heat Pipes

**Speaker: P. Diaz Gomez Maqueo**

Primary Author: Pablo Diaz Gomez Maqueo [1]

Co-Authors: Chukwudi Azih [1]; Reilly Maccoy [1]; Rory Mcgrath [1]

*[1] Canadian Nuclear Laboratories*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 380**

**Abstract**

Heat pipes are self-contained two-phase passive cooling devices. Microreactor concepts configure heat pipes in parallel banks (arrays) to transport heat away from the core and into power generating working fluid. The array heat pipe experiment at the High Temperature Fuel Channel Laboratory (HTFC) of the Canadian Nuclear Laboratories (CNL) simulates such configuration using 12 electrically-heated channels to simulate the heat generated from the nuclear fuel and five cooling channels with heat pipes to remove the heat. The core is simulated as a stainless-steel block. Power output is measured using a gas-cooled stainless steel block at the opposite end of the heat pipe array. Of the five heat pipes, three can be turned-off by injecting a non-condensable gas into them. An initial experiment to benchmark the performance of the array heat pipe was conducted and used as a baseline to compare with the subsequent cases. Experiments were then conducted by selectively turning off heat pipes in the array. The results of these tests show the heat distribution differences when compared with the baseline, and the effect of heat pipe failure when used in an array configuration.

# newcleo’s R&D Programme in support of SMR-LFR Development and Deployment

**Speaker: L. Cinotti [1]**

Primary Authors: Luciano Cinotti [2]; Andrea Barbensi [2]; Antonio Toti [2]; Fabio Moretti [2]; Mariano Tarantino [3]; Ulisse Pasquali [4]

*[1] TBC; [2] newcleo; [3] ENEA; [4] SRS*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 390**

**Abstract**

newcleo is designing MOX-fuelled SMR-LFRs, aiming at commissioning a MOX production plant and a demonstrator in the early 2030s, followed by a 200MWe First-Of-A-Kind and a fleet. The strengths of newcleo's reactor are safety, simplicity, compactness and cost competitiveness. These rely on lead properties and are enhanced by our innovative solutions, resulting in the elimination of several components no longer needed. A broad R&D programme supports the company’s incremental strategy to consolidate mature technologies and close existing gaps. This is implemented in partnership with ENEA, and benefits of the subsidiaries SRS-Fucina’s know-how. The main technical areas include: structural materials, coatings, primary components integrity/performance, handling systems, ISI&R and integral testing in large-scale facilities. Specific R&D needs are addressed through the refurbishment of existing ENEA infrastructure (e.g. NACIE loop for studies on heat transfer, CIRCE pool for components and SG tube rupture tests), and several new test facilities: - Corrosion Capsules (CAPSULE) in stagnant lead - Lead loop for corrosion and erosion tests (CORE) in flowing lead - Lead loop for thermal-hydraulic investigations and component testing (OTHELLO) - Dip-cooler instability (DCI) facility for thermal-hydraulics studies on bayonet-tube DHR - MANUT infrastructure for handling equipment testing/qualification - Pool-type large-scale integral test facility (Precursor,~10MW)

# Microreactor Applications, Research, Validation, and Evaluation (MARVEL) Reactor – Status, Construction, and Testing


**Speaker: J. Jackson [1]**

Primary Author: John Jackson [2]

Co-Authors: Abdalla Abou Jaoude [2]; Michael Patterson [2]

*[1] TBC; [2] Idaho National Laboratory*


**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 402**


**Abstract**

This paper presents the current status of the Microreactor Applications, Research, Validation, and Evaluation (MARVEL) microreactor design, qualification testing, fabrication, and high-level construction schedule. An overview of initial criticality, low power physics testing, and start-up testing is included, as well as an overview of the envisioned processes in which end-users can engage the project for access to operational data or specific demonstrations. Designed by the Idaho National Laboratory (INL) under the auspices of the US Department of Energy's Microreactor Program for construction and operation at the INL, MARVEL is a small, fully functional advanced reactor with UZrH fuel and thermal output of 85 kW. It offers a unique opportunity for scaled demonstrations that can dramatically accelerate the design, licensing, and deployment of commercial microreactors for power production or process heat applications. MARVEL's objective is to build a small liquid-metal thermal reactor at the INL to demonstrate design and operating processes for microreactors, microgrid integration, and process heat applications. MARVEL finished 90%-final-design in September 2023 and completed an independent project assessment in early 2024. Fabrication of long-lead components and fuel, safety analysis review, and procurement for construction are underway. MARVEL assembly and construction will start in 2025 and fuel loading is expected in early 2026. Initial criticality will be performed in a dry condition late in 2026, followed by loading of NaK coolant and start-up testing. Approximately six months later, release for unrestricted operations will enable

subsequent testing of microreactor characteristics, microgrid integration and select heat extraction applications.

# The Fast Modular Reactor

**Speaker: R. Faibish**

Primary Authors: Ron Faibish [1]; Hangbok Choi

*[1] General Atomics*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 403**

**Abstract**

The Fast Modular Reactor (FMR) is a 100 MWt (44 MWe) Gas-cooled Fast Reactor (GFR) being developed by General Atomics Electromagnetic System (GA-EMS). The goal is to develop a safe, flexible, economic, and dispatchable power source to the US and international electricity market by the mid-2030s. The technologies selected for the FMR to achieve these goals include: fast neutron spectrum that provides a long (>10 years) fuel cycle; helium coolant that is an inert gas with that does not chemically interact with any reactor component; conventional uranium dioxide (UO2) fuel which is the most well-known; silicon carbide (SiC) composite (SiGA®) cladding and internal structures which are exceptionally radiation tolerant; and closed Brayton cycle that provides a very high thermal efficiency (>42%). The reactor was specifically designed with passive safety features, including high-temperature in-core materials and reactor vessel cooling system (RVCS) consisting of cooling panels of naturally-circulating water. The passive safety of the core was confirmed for the unlikely abnormal accident of depressurized loss of forced cooling (DLOFC). The power maneuvering and load-following capability of the FMR was verified by a plant simulator, that incorporates the reactor kinetics and the power electronics of the power conversion system. During load-following operation, the variation of the core temperature is kept to a minimum by design. The conceptual design of the plant has been supported via a cooperative agreement with the U.S. Department of Energy.

# Accelerating Microreactor Development and Deployment Through Joint Public Testbeds and Private Advanced Reactor Development

**Speaker: T. Burnett**

Primary Author: Philip Schoonover

Co-Author: Troy Burnett [1]

*[1] Idaho National Laboratory*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 406**

**Abstract**

# Accelerating Microreactor Development and Deployment Through Joint Public Testbeds and Private Advanced Reactor Development **Philip Schoonover<sup>1</sup>, Troy Burnett<sup>1</sup>** <sup>1</sup>Idaho National Laboratory, Idaho Falls, ID ## ABSTRACT The United States Department of Energy (DOE) has funded the National Reactor Innovation Center (NRIC) to build two strategic assets at the Idaho National Laboratory (INL) to facilitate public-private partnerships for the development and testing of advanced nuclear reactors. One testbed provides a safe, secure, and affordable location for High-Assay Low Enriched Uranium (HALEU) fueled reactors and a second for Highly Enriched Uranium (HEU) fueled reactors. Together, these testbeds fill a nuclear testing infrastructure gap by retrofitting existing infrastructure, accounting for design considerations most useful to facilitate technical cooperation with industry partners. The availability of comprehensive testing facilities eliminates the significant financial and operational burdens associated with each developer building and licensing their own test facilities. This approach not only accelerates technological innovation and reduces time-to-market for advanced nuclear solutions but also underscores DOE's commitment to fostering an ecosystem where nuclear energy can thrive as a clean, reliable, and efficient source of power. The Demonstration of Microreactor Experiments (DOME) and Laboratory for Operations and Testing in the United States (LOTUS) have planned availability in 2026, and 2027 respectively. The availability of these testbeds and the associated ecosystem of

facilities and subject matter expertise are critical to microreactor deployment and commercialization. **Keywords:** NRIC, INL, Microreactor, DOME, LOTUS

# Digital Twin Technology based Modeling of Small Modular Reactor for early deployment within power Energy Systems

**Speaker: S. Touati**

Primary Author: Abdelkader Bouhlal

Co-Authors: Aissa Souli; Said Touati

**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 423**

**Abstract**

The Small modular reactors (SMRs) defined based on the output nuclear power plant rate, typically less than 300 MW), are an emerging nuclear power plant technology, suitable for large grids as well as remote load centers and offer load following and frequency response capabilities. Detailed dynamic models including reactor dynamics are necessary for power system dynamic studies. These reactors provide a broad range of applications beyond the electrical system, possibly addressing partial or full thermal power to cogenerate applications, such as heating, hydrogen generation, and desalination. Several nations are developing small modular reactors (SMRs) to incite the use of nuclear energy in the world's energy matrix to meet future energy demands and environmental standards. These reactors aim for the deployment of innovative nuclear technologies in energy systems by several advantages (security, safety, waste management, adapting plant output to increase operating flexibility...etc.). While many advanced models are being developed for SMRs, very few attempts have been made to develop a model that adequately represents the reactor dynamics in electric grid-integration studies with an appropriate pressurizer, steam generator and turbine models. The aim of our work reinforces this attempt to develop a model contributing to the early deployment of SMR any power systems energy. The simulation process of the proposed model will be validated experimentally using the Digital Twin Digital technology by using hardware-in-the-loop technique, which consisted of the modeling being integrated into the hardware and tested using real-time simulators. The proposed system will be designed and adapted to be easily integrated with existing microgrid systems to represent the behavior of an SMR in nuclear-power energy systems, avoiding high investments and complexity in testing and implementing actual nuclear reactors.

Keywords: small modular reactor; Digital twin technology; hardware-in-the-loop; nuclear power energy systems; modeling and simulation.

# A Digital Solution to Support Site Selection and Resilience of Advance and Small Modular Reactors Installation

**Speaker: T. J. Bhor**

Primary Author: Khwansiri Ninpan

Co-Authors: Mohamad Ali Assad; Lies Benmiloud Bechet; Tejas Jayram Bhor; Jean-francois Bossu; Olivier Vincent

**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 424**

**Abstract**

This paper proposes a novel recommendation tool for evaluating potential installation sites for Advanced and Small Modular Reactors (AMRs and SMRs) considering a multidimensional perspective. It combines various types of spatial and non-spatial data into the Geographic Information System at a 0.12 km² resolution, incorporating diverse parameters including transportation infrastructure, topography, water access, and geohazards. The tool offers flexibility for users to define the decision variables and assign weights reflecting their relative impacts. Leveraging multi-objective optimization, it potentially presents the Pareto frontier and provides a user-specific ranking of geographic areas. For broader applicability, the tool employs a digital twin-based assessment of potential interactions with existing electrical grids. The DIgSILENT simulator enables comprehensive power system analysis, encompassing diverse studies such as load flow, consumption, and contingency assessment. Furthermore, it incorporates climate predictions, such as sea surface temperature and sea level rise, to account for the multi-decade lifespans of SMRs. Additional relevant variables can be integrated based on user requirements to maximize project resilience. In conclusion, our approach accelerates the development and deployment of AMRs and SMRs to meet the growing global energy demand. Through a holistic site selection process, our solution provides an innovative framework for sustainable energy management.

# The Rosatom Technical Academy experience in the field of advanced personnel training for NNP with SMR

**Speaker: A. Diachenko**

Primary Author: Anton Diachenko [1]

*[1] Rosatom Technical Academy*

**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 37**

**Abstract**

One of the key conditions for the NPP safe operation is the availability of qualified personnel with appropriate specialized training and necessary certification and permissions, including those obtained from national regulatory authority. In order to provide facilities with operational personnel in a timely manner, the so-called advanced training is carried out at the construction phase, directly related to the NPP construction and commissioning schedule, based on the recognized systematic approach to training (SAT) of personnel. However, the features of the design, construction and commissioning of NPP with innovative SMR's require a number of features on the process of personnel training that are different from the classic SAT. Currently, the Rosatom Technical Academy has been implementing an integrated approach to the NPP operational personnel training, which consists of the development and support of a personnel training system - from the development of management documentation to training of licensed NPP personnel. This report presents the experience of the Rosatom Technical Academy related to crew training for the floating nuclear thermal power plant "Akademik Lomonosov", as well as the specifics of a personnel training system development for Generation IV NPP with BREST-OD-300 reactor.

# Analysis of the new RCC-MRx methodologies for creep-fatigue damage

**Speaker: A. Martin**

Primary Authors: Vincent Barbe [1]; Jean Caio Macedo Alves De Lima [2]; Antoine Martin [2]

*[1] EDF; [2] Framatome*

**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 84**

**Abstract**

The design and construction rules for mechanical components of nuclear installations (RCC Codes) published by AFCEN primarily apply to safety class components. RCC-MRx code was developed for sodium-cooled fast reactors (SFR), experimental reactors and fusion reactors but can be used, on condition that the rules applicability is justified, for components for other nuclear installations including the others GEN IV reactors (gas-cooled fast reactors, lead-cooled fast reactors, molten salt reactors, supercritical-water-cooled reactors and very high-temperature reactors). Its specificities are to propose rules for significant creep and significant irradiation domains. In the 2022 version, the RCC-MRx code introduced new methodologies to calculate more precisely the creep-fatigue damage of a loaded structure. In a first part, the article presents these new methodologies and their characteristics. Then, they are tested on structures whose design and operating loadings are representative of SFRs. Comparisons between the historical and the new methodologies are performed. In conclusion, the results show important gains on creep-fatigue damage by using the new methodologies, even if some local areas still present damages higher than allowable limits for a long-life duration. Nevertheless, it allows the designers to focus their work on these few areas.

# The ARCHEOS heat unit to decarbonize the heat market with proven technologies


**Speaker: F. Morin**

Primary Authors: Clément Liegeard [1]; Franck Morin [1]

Co-Authors: Philippe Amphoux [1]; Thierry Cadiou [1]; Laura Matteo [1]; Paolo Olita [1]

*[1] CEA*


**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 1: Design and Technology Development of SMRs (A.1)

**INDICO Abstract ID: 88**


**Abstract**

The ARCHEOS SMR is under development in the CEA. Currently under conceptual design phase, the ARCHEOS objective is to decarbonize the heat market in Europe for low temperature applications such as food industry, pulp and paper and chemistry. In 2024, a new structure regrouping industrial partners will host the ARCHEOS development. ARCHEOS is a Light-Water Reactor powering 50MW of heat to industrial networks. The main compromise on the ARCHEOS design, allowing reaching the economic target, is the supply temperature around 150°C. The reactor operates below 15 bar and uses new inherent safety feature. The thermalhydraulic design use natural convection on the primary and secondary circuits for normal operation. The primary circuit is an integrated vessel connected to compact heat exchangers directly linked to the vessel. A second vessel containing the secondary volume is around the primary vessel and contains a hot zone and a cold zone separated by a thermocline. The secondary circuit is thus in natural convection between the primary/secondary heat exchanges and the thermocline. This particular design leads to new thermalhydraulic operation of the reactor and a very high degree of safety: various accidents studied for LWRs do not exist for ARCHEOS and a thermal inertia will absorb the vast majority of postulated accident for ARCHEOS.

# Track 2: Advanced fuels, reprocessing, waste management and decommissioning aspects for SMRs – Safety, Design and Technology (A.2)

## Effect of changing the outer fuel element diameter on thermophysical parameters of RITM-200 reactor unit.

**Speaker: S. Alhassan**

Primary Authors: Samiru Alhassan [1]; Sergey Beliavskii [2]

Co-Author: Vladimir Nesterov [2]

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**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 2: Advanced fuels, reprocessing, waste management and decommissioning aspects for SMRs – Safety, Design and Technology (A.2)

**INDICO Abstract ID: 6**

**Abstract**

Abstract – The thermophysical calculation on the RITM-200 reactor unit is conducted to ascertain the possibility of optimizing the fuel element diameter without compromising the thermal constrains. The calculations included temperature distribution profile of fuel elements at various fuel element diameters, average coolant velocities and critical heat flux for nucleate boiling crisis analysis. It is demonstrated from the results achieved that an inverse relationship exists between fuel element diameter and maximum fuel temperature. The average coolant velocity is directly proportional to fuel element diameter at a constant flowrate of G =9.38 kg/s. It is also determined that decreasing the fuel element diameter below 6.9 mm will lead to boiling crisis.

# WASTE MANAGEMENT OF THE FUEL CYCLE ON THE IMPLEMENTATION OF SMR PROJECTS IN UKRAINE

**Speaker: B. Zlobenko**

Primary Authors: Yuriy Zabulonov [1]; Borys Zlobenko [1]

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**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 2: Advanced fuels, reprocessing, waste management and decommissioning aspects for SMRs – Safety, Design and Technology (A.2)

**INDICO Abstract ID: 11**

**Abstract**

To mitigate global climate challenges, using Small Modular Reactors (SMRs) has an interest in Ukraine to replace coal-fired generation. Ukrainian NAEC "Energoatom" is considering deploying a series of SMRs with localisation of reactor installation and components manufacturing in Ukraine. The signed agreements for cooperation in concluding contracts, licensing, and constructing up to 20 LWR SMRs. The fuel and materials selection process has a major impact on the feasibility of reactor concepts. The fissile isotope enrichment levels will equal or exceed conventional LWR fuel. Handling SNF during the implementation of SMR projects in Ukraine requires special attention due to the uncertainty of the back end of the fuel cycle. The conceptual handling of SMR SNF can be borrowed from technology currently known as SNF of WWR-type reactors. Safety studies of new types of Spent Fuel will be required to assess its behaviour for long-term storage. The most economical SF management approach for LW SMRs will require integration with existing back-end technologies and facilities. Participation in the European Joint Programme "EURAD-2" and IAEA CRP ‘’Challenges, Gaps and Opportunities for Managing Spent Fuel from Small Modular Reactors” allows collaboration towards safe SF and radioactive waste management in implementing Geological Disposal.

# Designing small modular reactors for a circular economy

**Speaker: K. Gillin**

Primary Author: Kristina Gillin [1]

*[1] Vysus Group*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 2: Advanced fuels, reprocessing, waste management and decommissioning aspects for SMRs – Safety, Design and Technology (A.2)

**INDICO Abstract ID: 16**

**Abstract**

As part of striving for sustainable development, awareness is growing that the world needs to shift from a linear to a circular economy. A circular economy is enabled through design and goes beyond the waste hierarchy, as it aims to eliminate waste altogether. Things are also designed to last longer and be easier to repair, reuse, repurpose and recycle. Given the ambitions to contribute to sustainability, the nuclear industry now has a window of opportunity to ensure that the many small modular reactors that are anticipated to be constructed over the coming decades are designed for a circular economy. That is, to align with sustainability principles, small modular reactors need to be designed not only for decommissioning but also for circularity. By taking a lifecycle approach, the paper will present a set of design principles for small modular reactors in a circular economy. Opportunities and challenges with designing reactors for circularity will also be discussed.

# Conclusions from SFM'24 Conf on challenges and issues in managing spent fuels from SMRs

**Speaker: A. Gonzalez Espartero**

Primary Author: Amparo Gonzalez Espartero [1]

*[1] IAEA*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 2: Advanced fuels, reprocessing, waste management and decommissioning aspects for SMRs – Safety, Design and Technology (A.2)

**INDICO Abstract ID: 64**

**Abstract**

This is a place holder to include here a summary of the conclusions from the IAEA International Conference on Spent Fuel Management 2024 to be held on 10-14 June 2024 where there is a TRACK dedicated to discussing the management of SNF from SMRs including all technologies envisaged today.

# Facilitating SMR fuel fabrication from HALEU UF6

**Speaker: M. Sokcic-kostic**

Primary Author: Marina Sokcic-kostic

Co-Authors: Christopher Reiser; Karl Froschauer; Georg Braehler

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 2: Advanced fuels, reprocessing, waste management and decommissioning aspects for SMRs – Safety, Design and Technology (A.2)

**INDICO Abstract ID: 126**

**Abstract**

Sourcing oxidic high-assay low-enriched uranium (HALEU) from down blended highly enriched uranium (HEU) has no prospects. Therefore, correspondingly enriched UF6 must be considered as main input material for fuel production plants. NUKEM gained experience as operator of fabrication plants for all common fuel types. Designs for facilities can be offered based on this knowledge. Deconversion from UF6 into an oxidic form is achieved via AUC conversion. This process yields UO2 with beneficial properties, which can be directly utilized for light water SMR pellets. UO2 can be fluorinated to UF4, which is ready to be applied in a molten-salt SMR. Finally, metallic uranium can be produced via calciothermic reduction of UF4. Uranium metal can be alloyed to fuel SMRs like the sodium-cooled fast reactor (SFR). Alternatively, UO2 can be calcined to yield the raw material of HTR TRISO-fuel production plants. Beginning from the dissolution of U3O8, fuel compacts or pebbles can be manufactured. The prerequisite of a criticality-safe process keeping state-of-the-art radioprotection standards is fulfilled for HALEU material up to 20 % enrichment. Reprocessing of uranium and chemicals for zero emission is included within the process. NUKEM is capable to design industrial scale facilities with throughputs of several tons of uranium per year.

# Empowering Emerging Nuclear Nations: Wastimate's Open-Source Approach for Small Modular Reactor Radioactive Waste Management

**Speaker: H. Tohver**

Primary Author: Hando Tohver [1]

Co-Authors: Marti Jeltsov [2]; Siiri Salupere [1]

*[1] University of Tartu; [2] National Institute of Chemical Physics and Biophysics*

**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 2: Advanced fuels, reprocessing, waste management and decommissioning aspects for SMRs – Safety, Design and Technology (A.2)

**INDICO Abstract ID: 134**

**Abstract**

Countries embarking on nuclear technology face challenges in evaluating waste burdens due to limited expertise and tools. Government-level decisions are further complicated when SMR's enter the picture – the lack of large-scale fleet deployment limits already lacking information on radioactive waste management. In order to provide more information on waste quantities, characteristics, optimal management, and disposal means, a novel and easy-to-use waste estimation software, Wastimate, has been created using Python. The open-source waste package tracking software is implemented with a large degree of automation, making it possible for radiation protection specialists and other stakeholders to conduct general waste system studies. Its design allows for the modeling of non-standard scenarios, including SMR deployment in emerging nuclear nations. Recognizing the absence of benchmarks specifically tailored to waste disposal systems, one is proposed with a focus on nuclear waste disposal and management. Demonstrating its versatility, Wastimate is effective in modeling waste quantity, activity, decay heat, and isotope flow over time, even under uncertain conditions. By providing comprehensive insights into complex systems, Wastimate empowers policymakers to navigate the complexities of nuclear waste management and make well-informed choices regarding the adoption and implementation of SMRs in emerging nuclear nations.

# Investigation of hydrodynamic and scaling of TRISO coaters for high temperature small modular reactors

**Speaker: T. Aljuwaya**

Primary Authors: Thaar Aljuwaya (nuclear Science Research Institute, King Abdulaziz City For Science And Technology, P.o. Box 6086, Riyadh 11442, Saudi Arabia [1]; Ahmedg@kacst.edu.sa [2]; Asalomari@kacst.edu.sa) [3]

Co-Author: Muthanna Al-dahhan [4]

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**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 2: Advanced fuels, reprocessing, waste management and decommissioning aspects for SMRs – Safety, Design and Technology (A.2)

**INDICO Abstract ID: 175**

## Abstract

The quality of TRISO-coated nuclear fuel particles is crucial for ensuring operational efficiency and safety of high-temperature gas-cooled small modular reactors (SMRs) that utilize TRISO technology. This is why the TRISO particles must be uniform in size, shape, and coating, as well as free of defects. The technique used for coating TRISO particles are gas-solids spouted beds via chemical vapor deposition (CVD). It has been reported that the quality of TRISO coated particles is strongly affected by the hydrodynamics of the spouted beds. The gas-solid spouted bed coating technology, integral to TRISO particles, is examined, with a focus on the impact of spouted bed hydrodynamics on the delicate coating layers surrounding the fuel kernel. The intricate interplay between successive coating layers and the scaling up of spouted beds, vital for large-scale TRISO particle fabrication for SMRs, represents a significant challenge in nuclear fuel particle manufacturing. In response to this challenge, our study presents our newly developed mechanistic scale-up methodology for gas-solids spouted beds, validated through an experimental examination of radial gas holdup profiles using sophisticated measurement techniques. This methodology is a pivotal advancement in understanding hydrodynamics and scale-up dynamics, crucial for the commercialization of SMRs utilizing TRISO technology. In light of current nuclear fuel requirements for

SMRs, this research is of utmost importance due to the escalating demand for TRISO particles. Furthermore, our work presents a comparative analysis between the mechanistic scale-up methodology developed in our laboratory and traditional approaches, demonstrating the enhanced accuracy of the former in predicting the performance of spouted bed systems. The insights derived from this study hold significant implications for the development and commercialization of high-temperature gas-cooled SMRs employing TRISO technology, offering valuable contributions to the broader context of clean and sustainable energy solutions.

# Scoping calculation of spent nuclear fuel from NuScale’s Power Module


**Speaker: T. Yildirim**

Primary Author: Martin Amft [1]

Co-Author: Tugba Yildirim [2]

*[1] Sydkraft Nuclear Power AB; [2] WSP Sweden AB*


**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 2: Advanced fuels, reprocessing, waste management and decommissioning aspects for SMRs – Safety, Design and Technology (A.2)

**INDICO Abstract ID: 252**


**Abstract**

The Swedish Nuclear Fuel and Waste Management Company is tasked with the construction and operation of geological repositories for spent nuclear fuel and radioactive waste from the existing fleet of Sweden’s nuclear power reactors. In the Swedish government’s roadmap for a nuclear new-build program, both large-scale and small modular reactors are envisioned. Amongst many other aspects, the management and disposal of spent nuclear fuel and radioactive waste from these new reactors have to be planned and financed. Scoping calculations for the expected waste types are a crucial input to the decisions how to extend or adapt the current system for waste management and disposal. In the present study, as an example, the amount of spent nuclear fuel arising during the lifetime of a light water small modular reactor, namely, NuScale’s Power Module, an integral pressurized water reactor with 160 MWth of thermal power, was calculated. Serpent, a multi-purpose three-dimensional continuous-energy neutron and photon transport Monte Carlo code, was used to model the equilibrium core of a NuScale Power Module and to calculate the amount of spent nuclear fuel and its discharge burnup. According to the performed scoping calculations, a single Power Module would give rise to 96 metric tons spent nuclear fuel after 60 years of operation. The average discharge burnup was calculated to be approximately 37 GWd/t-U.

# Characterisation of spent LWR fuel with SMR-relevant initial compositions and operational conditions

**Speaker: G. Žerovnik**

Primary Author: Gaå¡per Žerovnik

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 2: Advanced fuels, reprocessing, waste management and decommissioning aspects for SMRs – Safety, Design and Technology (A.2)

**INDICO Abstract ID: 299**

**Abstract**

Currently, there is a large number of Small Modular Reactor (SMR) concepts in different stages of development. Among them, many are Light Water Reactors (LWRs). To counteract their smaller size compared to the »classical« GEN II and III conterparts, various design adaptations are being proposed, e.g. the use of High-Assay Low-Enriched Uranium (HALEU) fuel and different reflectors. In addition, operational parameters may differ, e.g. having a lower power density and an enhanced ability to operate in so-called load-following mode. These modifications affect the composition of spent nuclear fuel (SNF), which has implications with respect to high-level radioactive waste and resource utilisation. The aim of this paper is to investigate some key aspects of fuel depletion. Assuming a generic SMR-relevant design, it explores the relationship between neutron multiplication factor and reactor core size, examines the maximum achievable burnup considering different types of reflectors and initial U-235 enrichments. Additionally, some important components of the SNF nuclide vector are compared, along with integral parameters like decay heat and neutron emission. All calculations are performed with Serpent neutron transport and fuel depletion code using the ENDF/B-VII.1 nuclear data library.

# CAREM 25 fuel cycle optimization and ATF evaluation

**Speaker: H. Lestani**

Primary Author: Héctor Lestani [1]

Co-Authors: Juan Bergallo [2]; Edmundo Miguel Lopasso [2]

*[1] CNEA - Argentina; [2] CNEA*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 2: Advanced fuels, reprocessing, waste management and decommissioning aspects for SMRs – Safety, Design and Technology (A.2)

**INDICO Abstract ID: 309**

**Abstract**

The use of Accident Tolerant Fuels (ATF) is evaluated from the neutronics and economics points of view as a means for enhancing reactor safety while maintaining competitiveness of the CAREM 25 nuclear fuel cycle. The ATF evaluated consists on the use of FeCrAl cladding and keeping UO2 and Gadolinia Burnable Poison (BP) as the fuel it self. The FeCrAl cladding has the outstanding advantage of avoiding the Hydrogen production that results from Zirconium oxidation of conventional Zircaloy claddings undergoing overheating. However, the use of FeCrAl imposes a considerable increase in absorptions that has to be counter balanced with an increase in Uranium enrichment. Particular features of SMR cores, such as their small sizes and “boron-free” designs along with a smaller amount of control rods available, impose tighter restrictions to power distribution and reactivity control. The fuel design is hence optimized from the neutronics point of view to comply with design requirements, which leads to a concentration of BPs adjusted for every enrichment chosen, while the optimum enrichment level results from an economic optimization. Therefore, results of burnable poison and enrichment optimizations, as well as their consequence in the decrease of the reactivity worth of control rods, are presented in this paper.

# newcleo's Fuel Cycle innovations for SMR-LFR including transport of fresh and spent fuels

**Speaker: J.-m. Marin [1]**

Primary Authors: Jean-michel Marin [2]; Luciano Cinotti [2]; Dominique Favet [2]; Brian Nixon [2]; Christian Dupont [2]

*[1] TBC; [2] newcleo*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 2: Advanced fuels, reprocessing, waste management and decommissioning aspects for SMRs – Safety, Design and Technology (A.2)

**INDICO Abstract ID: 391**

**Abstract**

newcleo is designing SMR-LFRs fuelled with uranium and plutonium mixed oxide (MOX). A novel approach is envisioned to better use the fissile nuclear material from the current fuel cycle. newcleo is planning to design, build and operate a state-of-the-art MOX fuel facility versatile and modular in nature with an innovative concept to cope with radiological and nuclear thermal effects in order to consume and re-use plutonium bearing materials either already in separated inventories or to be reprocessed in the future, with a focus on fissile material without an already established and existing recycling scheme. In view of implementing its long-term vision, newcleo will also reinstitute a complete supply chain adapted to Fast Reactors and as a part of it, newcleo will develop innovative and adapted transport cask solution and logistics to support all the globally needed shipments. In summary, newcleo is presenting a comprehensive view of a closed fuel cycle encompassing multi-recycling in its LFRs with country specific solutions to operate synergistically with existing nuclear fleets, with the overall goal of moving towards a more sustainable nuclear fuel cycle and thus a reduction in the radiotoxicity and volume of the final waste.

# The Development of a Versatile Type B(U)F Transport Package to Support the Front-End Fuel Cycle of Gen-IV Reactors

**Speaker: A. Lever [1]**

Primary Author: Sean Perry [2]

Co-Author: Adam Lever [2]

*[1] TBC; [2] Nuclear Transport Solutions*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 2: Advanced fuels, reprocessing, waste management and decommissioning aspects for SMRs – Safety, Design and Technology (A.2)

**INDICO Abstract ID: 76**

**Abstract**

NTS is the leading global provider of safe, secure and reliable nuclear transport and logistics solutions that help make the world safer and more sustainable. We support the global nuclear market by providing standalone or end-to-end solutions to nuclear transport and logistics challenges. NTS have been successful in receiving funding from the Department for Energy Security and Net Zero (DESNZ) Nuclear Fuel Fund (NFF) to develop a new IAEA SSR-6 compliant transport package. The package shall be designed to transport High Assay Low Enriched Uranium (HALEU) in multiple forms to support the front-end fuel cycle of the UKs Gen-IV Advanced Modular Reactor (AMR) development strategy. Due to the UKs history of operating gas cooled reactors, the Gen-IV reactor technology of choice is likely to be a High Temperature Gas Cooled Reactor that utilizes TRISO fuel. The HALEU Transport Package (HTP) has been designed with an interchangeable basket to allow an array of contents to be transported. As Gen-IV reactors are still in development, the fuel specification and design are not yet fixed. Therefore NTS have focused on the transport of HALEU powder (U235 ≤ 20% enrichment) in cans from deconversion facilities to fuel manufacturing facilities. The package incorporates features from a number of existing NTS package designs and utilizes both a Multiple Water Barrier and Commercial off the Shelf material to simplify package licensing and manufacture. This paper provides an overview of the HTP design

with a focus on the challenges of developing a package with an assumed contents specification.

## Track 3: Engineering, Codes & Standards, Supply Chain, Operation and Maintenance of SMRs (A.3)

# Addressing SMRs safety I&C specific requirements

**Speaker: A. Duthou**

Primary Author: Arnaud Duthou

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 3: Engineering, Codes & Standards, Supply Chain, Operation and Maintenance of SMRs (A.3)

**INDICO Abstract ID: 251**

**Abstract**

SMRs development is entering a critical phase where initial assumptions are challenged by current operational constraints. Indeed, the combined requirements of safety and computer security, industrial supply chain setup, varying local safety regulations and multiple markets targeted besides electricity production is causing revaluation of their standardization objectives and ultimately their business cases. We propose to demonstrate that carefully designed architectures and technologies can resolve this equation for SMRs safety I&C while guaranteeing safety and computer security. First, the I&C systems provided shall be compact and modular to meet SMR footprint constraints, for that scalable technologies that can adapt to both individual reactor and shared functionalities between coupled reactors shall be used. To ensure limited footprint and cabling, these technologies shall be able to provide remote IO capacities, compact form factor and adaptable to multiple cabinets and enclosures format. To match SMR fleet approach, the I&C components shall be manufactured/programmed in series to limit costs and shorten production time, this implies a strong standardization strategy while keeping room for customization to meet specific needs of various plant designers and different nuclear authorities. In addition, to support licensing in all countries targeted, a proven architecture, compliant engineering lifecycle covering design and V&V, cybersecurity, HMI features and experience will facilitate acceptability. Leveraging more than 60 years of international experience designing, manufacturing, and installing safety I&C systems for various types of NPPs, Framatome has designed new safety I&C technologies meeting SMR constraints, in particular: TXS compact, an FPGA-based

digital technology and Hardline, a purely Hardwired platform. We will present what key characteristics make them optimized solutions for SMR safety and cybersecure I&C needs.

# Flexibility limits of SMRs using HALEU for enhanced load-following

**Speaker: S. Choudhury**

Primary Author: Shiny Choudhury

Co-Authors: Michael Davidson [1]; George Tynan [1]

*[1] UC San Diego*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 3: Engineering, Codes & Standards, Supply Chain, Operation and Maintenance of SMRs (A.3)

**INDICO Abstract ID: 353**

## Abstract

VRE sources like solar and wind have high intermittency and with large shares of them, thermal generators would need to match the net load curve rather than the demand curve or need to perform VRE-following. The French experience [2] and existing literature, including works by Jenkins et al. [3] and Ponciroli et al. [4], primarily focus on load-following in large reactors, in scenarios with low VRE penetration, revealing a gap in the context of VRE-following, especially for SMRs. Current operational constraints limit NPPs' by allowing a shift from 100% to 50% and back to 100% of rated power once in 24 hours [1]. However, nuclear reactors inherently possess a substantial reactivity reserve, enabling them to closely load-follow for a significant portion of their irradiation cycle. We perform reactor physics numerics for enhanced VRE-following from beginning-of-life (BOL) to end-of-life (EOL) for PWR-SMRs, considering burnup, enrichment, ramp limits, declining reactivity, Xenon poisoning-induced deadtimes, and minimum power levels. We use the insights in a modified Unit Commitment model with a large amount of renewable energy. The objective is to establish a granular constrained operational space within which a nuclear reactor, specifically a GW-class AP1000, and the newly unveiled AP300 SMR, can perform VRE-following. REFERENCES [1] AP1000 ARIS Specifications n.d. https://aris.iaea.org/PDF/AP1000.pdf (accessed May 29, 2023). [2] Cany C, Mansilla C, Mathonnière G, da Costa P. Nuclear power supply: Going against the misconceptions. Evidence of nuclear flexibility from the French experience. Energy 2018;151:289–96. https://doi.org/10.1016/j.energy.2018.03.064. [3] Jenkins JD, Zhou Z, Ponciroli R, Vilim

RB, Ganda F, de Sisternes F, et al. The benefits of nuclear flexibility in power system operations with renewable energy. Appl Energy 2018;222:872–84. https://doi.org/10.1016/j.apenergy.2018.03.002. [4] Ponciroli R, Wang Y, Zhou Z, Botterud A, Jenkins J, Vilim RB, et al. Profitability Evaluation of Load-Following Nuclear Units with Physics-Induced Operational Constraints. Nucl Technol 2017;200:189–207. https://doi.org/10.1080/00295450.2017.1388668.

# PROGRESS OF STEEL CONCRETE STRUCTURES CODIFICATIONS FOR SMR


**Speaker: J. Niepceron**

Primary Author: Julien Niepceron [1]

Co-Authors: Manuel Corbin [2]; Boris Marquois [2]; Sophie Rallo-bremond [2]

*[1] NUWARD; [2] EDF*


**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 3: Engineering, Codes & Standards, Supply Chain, Operation and Maintenance of SMRs (A.3)

**INDICO Abstract ID: 66**

**Abstract**


Over the past few years, there has been considerable interest in the use of modular steel-concrete composite structures for the construction of buildings for nuclear power plant, especially out of Europe. Indeed, the use of steel concrete structures is known to shorten the construction duration, as it enables to reduce the number of tasks such as erecting the concrete formwork and installing reinforcements. There is also a major improvement regarding the challenges for equipment anchoring. AFCEN, which is an international association of companies from the nuclear energy sector, develop and adapt advanced rules to fit the specificities in relation with safety of this industry. A working group (WOG8 ) dedicated to Steel Concrete Structures has been created to write dedicated chapters in the Code RCC-CW (Rules for Design and Construction PWR Nuclear Civil Work). EDF's experience regarding the use of the Steel Concrete Structures through two European projects (SCIENCE & SCHEDULE) has allowed to draw some fundamental design and construction principles of standard sections and connections of steel concrete modules. In 2021, AFCEN has mandated EDF to produce a report gathering the "Technical Status on the Design and Construction of Steel Concrete Structures" (PTAN) to be used as a basis for the implementation of new chapters dedicated to Steel Concrete Structures in the next revision of the RCC-CW (expected to be issued on 2025). The Codification of the steel concrete technology strengthen the opportunity for future projects such as NUWARD SMR to use it, especially in safety

classified structures. This paper aims to present the main outcome of the European codification of SCS Structures.

# Challenges for serial deployment of SMRs: A certification body's point of view


**Speaker: E. Dagorn**

Primary Author: Erik Dagorn [1]

*[1] France*


**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 3: Engineering, Codes & Standards, Supply Chain, Operation and Maintenance of SMRs (A.3)

**INDICO Abstract ID: 114**


**Abstract**

Certification bodies and independent inspection agencies play a key role in demonstrating the safety of nuclear projects. They provide Testing, Inspection, Certification (TIC) services on a regulatory (mandatory) or voluntary basis, acting as “Third” or “Second” Party. They are accredited by “Accreditation Bodies” and approved by nuclear regulators who constantly audit their effective independence, their knowledge of regulations and their operational conformity assessment procedures (including the technical qualification of inspectors). Their roles and responsibilities are strictly defined by regulators who may chose to involve them at various stages of the project development, and for various technical scopes. In response to the anticipated strong development of nuclear projects worldwide, certification bodies and inspection agencies have to deal with numerous challenges. These challenges concern the number of projects but also the variety of technologies and the industrial organization specific to the serial construction of SMRs. Uncertainties about the regulatory environment remain the most significant risk factor. This paper describes how certification bodies and inspection agencies are now preparing to adapt their service offerings and processes for the success of SMRs deployment worldwide.

# Research on Digital Intelligent Operation and Maintenance Technology for SMR

**Speaker: L. Huang [1]**

Primary Authors: Jianxin Chen [2]; Weizu Xu [2]

*[1] TBC; [2] Hainan Nuclear Power Co.,Ltd*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 3: Engineering, Codes & Standards, Supply Chain, Operation and Maintenance of SMRs (A.3)

**INDICO Abstract ID: 158**

**Abstract**

Abstract: The SMR 'Linglong-1' (ACP100) developed by China National Nuclear Corporation (CNNC) has been favoured by domestic and international markets due to its inherent safety, flexibility of deployment and wide range of applications. This paper introduces the application of digital technology in the operation and maintenance of SMR on the premise of ensuring safety, improving the level of automation and intelligence in the operation and maintenance of small reactors through the research of intelligent operation and control technology, intelligent monitoring and diagnosis technology, intelligent inspection and surveillance technology, and intelligent maintenance and management technology, so as to enhance the advantages of SMR in the new round of nuclear energy technological change and international industrial competition.

# Advancing an Increasingly Critical Canada-USA HALEU Supply Chain for SMRs and Advanced Reactors

**Speaker: R. Tscherning**

Primary Author: Rudiger Tscherning

**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 3: Engineering, Codes & Standards, Supply Chain, Operation and Maintenance of SMRs (A.3)

**INDICO Abstract ID: 159**

**Abstract**

The IAEA has rightly been vocal about the need to develop alternative fuel supply chains for next generation SMR and advanced reactors. This paper will discuss the potential - and the barriers - to developing a strategic and coordinated Canada-USA HALEU supply chain by drawing on the key advantages of the respective Canadian and US nuclear sectors to secure alternative access to low enriched uranium, including HALEU supplies for the global nuclear economy. What role will regulatory coordination and harmonization play in fostering a scale-up of the cross-border HALEU supply chain? Is there potential for FIRST Program partners to secure preferred fuel access from North America and how can other new-nuclear countries secure their HALEU supplies from the USA and Canada?

# Development Strategy of HMI and Digital I&C System's Emulator for Korean Innovative SMR Plant

**Speaker: S. Lee**

Primary Author: Sungjin Lee [1]

*[1] Korea Hydro and Nuclear Power*

**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 3: Engineering, Codes & Standards, Supply Chain, Operation and Maintenance of SMRs (A.3)

**INDICO Abstract ID: 165**

**Abstract**

KHNP has developed an integrated emulator system for APR1400 MMIS based on hardware virtualization technology. Korean innovative SMR (i-SMR) has been developing now. Since new digital I&C platforms and various software systems will be adopted for i-SMR, their performance shall be verified and validated through an integrated prototype test-bed. One way to make the prototype test-bed is using virtualization and emulation technologies. Even though final system design will be determined later, the prototype can be implemented with generic I&C platform modules. This paper provide considerations and applications of this approach.

# Maintenance Strategy for i-SMR

**Speaker: H. Nam**

Primary Author: Hyunsuk Nam [1]

*[1] Korea Hydro & Nuclear Power Central Research Institute*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 3: Engineering, Codes & Standards, Supply Chain, Operation and Maintenance of SMRs (A.3)

**INDICO Abstract ID: 191**

**Abstract**

The innovative-SMR (i-SMR) being developed in South Korea has maintenance challenges due to its integral reactor design compared to conventional nuclear power plants. To overcome these limitations, the i-SMR has been designed with maintenance considerations. The maintenance procedure for the i-SMR includes several steps aimed at optimizing maintenance efficiency. The maintenance procedure for the i-SMR comprise the following steps : 1) Containment Vessel upper head disassembly & inspection (CV head is maintained at laydown area), 2) Reactor Closure Head disassembly & maintenance (Remove of CEDM/ICI penetration seal and increasing of level of refueling pool), 3) Reactor Vessel Internals (inner barrel assembly → upper guide structure → core support plate), 4) Transfer the fuel assembly to spent fuel pool, 5) Non destructive testing inspection for main component (UT inspection for RV/CV welds). These detailed steps allow the i-SMR to undergo maintenance in less time compared to conventional nuclear power plants. By prioritizing maintenance considerations in its design and implementing efficient maintenance procedure, the i-SMR demonstrates its potential to minimized overhaul time and maximized operational efficiency.

# Tailored MBSE Approach for SMR Gen IV Architecting

**Speaker: J. Bourdon**

Primary Author: Jeremy Bourdon [1]

Co-Authors: Lies Benmiloud-bechet [1]; Jean-françois Bossu [1]; Frédéric Cheneau [1]; Christophe Fournier [1]; Adrien Guerin [1]; Julien Jachmich [1]; Will Machin [1]; Robert Plana [1]; Olivier Vincent [1]; Angelo Zoino [1]

*[1] Assystem*

**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 3: Engineering, Codes & Standards, Supply Chain, Operation and Maintenance of SMRs (A.3)

**INDICO Abstract ID: 245**

**Abstract**

he accelerating energy transition requires rapid access to decarbonized sources. Although Gen IV SMRs present a potential solution, they face challenges such as complex licensing processes and architectural issues, as they must align with diverse global regulations and adapt to varied site-specific requirements, complicating standardization and deployment. In the face of these challenges, the need for a scalable, agile project structuring and organization is becoming increasingly apparent. This structure must be able to support the rapid expansion characteristic of Gen IV SMR projects, while also having the necessary flexibility to adapt to a dynamic reallocation of responsibilities. The core of our approach is the initial structuring of enterprise data models, core engineering processes and methodologies. By adopting a holistic Model-Based Systems Engineering (MBSE) approach that integrates key domains, with safety as the cornerstone, it is ensured that the resulting structuring of engineering data can meet demonstration expectations. In addition, we are discussing the creation of a nuclear-specific layer in numerical tools, enhancing the consideration of safety concerns during architecture definition. This materializes in the creation of a customized profile in an MBSE tool, which incorporates nuclear safety terminology and aligns with industry usage. By focusing on digital continuity, our approach guarantees a seamless transition between the various development phases, systems engineering processes and lifecycle phases. This means preserving the reliability of information (traceability) and promoting

uniform communication (modelling). The presentation will conclude by illustrating the potential benefits of our approach, particularly in safety demonstrations.

# Process Instrumentation for New Generation of Reactors

**Speaker: H. Hashemian**

Primary Author: Hashem Hashemian [1]

*[1] AMS*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 3: Engineering, Codes & Standards, Supply Chain, Operation and Maintenance of SMRs (A.3)

**INDICO Abstract ID: 258**

**Abstract**

Small Modular Reactors (SMRs) and Advanced Modular Reactors (AMRs) are different in their requirements for process instrumentation, especially sensors to measure temperature, pressure, level, flow, and neutron flux. SMRs are generally water cooled, low temperature and high pressure systems while AMRs are high temperature and relatively low pressure. Therefore, the type of process sensors to be used in these new generation of reactors are different and existing sensors from existing nuclear-grade sensor manufacturers may not work in these reactors without modification, requalification, and reconfiguration. This paper will describe how the new reactor vendors may navigate their sensor requirements, what must be measured to control these plants, and how to monitor for their safety and integrity. In addition, the paper will present a review of the latest developments in sensor technologies for new generation of reactors and will address the need for new standards for qualification and performance verification of these sensors. Furthermore, the paper will emphasize how liquid or gas flow rates may be measured in SMRs and AMRs as flow rate is among the important process variables in most new plants and generally more difficult to measure than other process variables.

# AI for Design, Engineering, Construction and Operation of SMRs

**Speaker: N. Prinja**

Primary Author: Nawal Prinja [1]

*[1] Jacobs Clean Energy*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 3: Engineering, Codes & Standards, Supply Chain, Operation and Maintenance of SMRs (A.3)

**INDICO Abstract ID: 272**

**Abstract**

This paper highlights, through examples, how innovative applications of digital technologies like AI/ML can help deploy SMRs in future. Examples are presented to demonstrate how AI/ML can help reduce time and cost in qualifying new materials, in improving efficiency in non-destructive testing during manufacture. Through real life examples, it is shown how AI-powered cognitive search engine can help manage knowledge flow from supply chain, extract data for effective Life Time Quality Records and help make safety cases.

# Nonlinear ultrasonic parameters to laser weld quality for Small Modular Reactor


**Speaker: H. Kim**

Primary Author: Hyunmyung Kim [1]

Co-Author: Jongbeom Kim [1]

*[1] FAINDUS Inc.*


**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 3: Engineering, Codes & Standards, Supply Chain, Operation and Maintenance of SMRs (A.3)

**INDICO Abstract ID: 276**


## Abstract

Abstract : Nonlinear ultrasonic testing (NUT) technique can be used to identify microscopic material properties over conventional (linear) UT owing to its high sensitivity in which the nonlinear parameters establish a set of signal pattern recognitions such as forming higher harmonic waves. To replace conventional SAW, ESW on cladding, implementation of laser cladding technique has been studied with advanced robotics to minimize machining surface and welding quality. In this study, a set of laser welding process was applied to stainless steel and the signals pattern processing algorithms were determined to identify the weld quality (such as inclusion, crack, incomplete fusion and penetration ) by means of nondestructive examination. Experimental correlations between laser weld microstructure and NUT signals were disccused in terms of the manufacturing SMR componenets. Keywords: Nonlinear ultrasonic, Nondestructive test, Laser welding, Signal processing algorithm

# The Status of Supply Chain for Small Modular Reactors deployment in China

**Speaker: S. Zhu**

Primary Author: Sheng Zhu [1]

*[1] Nuclear Power Operations Research Institute*

**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 3: Engineering, Codes & Standards, Supply Chain, Operation and Maintenance of SMRs (A.3)

**INDICO Abstract ID: 281**

**Abstract**

SMRs have the characteristics of small size, light weight, strong application flexibility, and low initial investment. They can be widely used in various scenarios such as power generation, heating, and seawater desalination, and are one of the important choices for achieving zero carbon energy. China began the technological research and development of SMRs in the early 1980s, targeting the application needs of heating in cold regions, power supply in remote areas, and seawater desalination in coastal areas. Various types, power levels, and technical characteristics of SMRs were developed. Among them, the 200MWe high-temperature gas cooled SMR has been put into operation in 2021, and the 125MWe "Linglong 1" integrated multi-purpose water cooled SMR is under construction ， and is planned to be completed for power generation in 2026, and several SMRs are in different research and development stages at current stage. China has established a complete supply chain system through more than 30 years of research and development, construction, and application practice in the field of SMRs, which can provide strong support for the deployment of SMRs. This article will introduce the status of SMRs supply chains in China from various aspects such as basic research and development, equipment manufacturing, construction and project management, operation and maintenance, and technical support. It will be helpful for the potential SMR users to understand China's capabilities in SMR deployment, and promote the large-scale application of SMRs.

# The IEC Standard Series on Cybersecurity for I&C and Electrical Systems For Operating and Small Modular Reactors

**Speaker: T. Walter [1]**

Primary Author: Tighe Smith [2]

Co-Authors: Edward Quinn [3]; Ludovic Pietre-cambacedes [4]; Thomas Walter [5]; Juergen Bochtler [6]; Michael Rowland [7]

*[1] TBC; [2] Paragon Energy Solutions; [3] Technology Resources; [4] EDF; [5] Preussen Elektra; [6] Siemens Energy; [7] Sandia National Laboratory*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 3: Engineering, Codes & Standards, Supply Chain, Operation and Maintenance of SMRs (A.3)

**INDICO Abstract ID: 292**

**Abstract**

ABSTRACT This paper provides an overview of the existing and new cybersecurity standards for I&C and Electrical Systems tailored for nuclear power plants, including SMRs, around the world. The IEC 62645 is a standard by the International Electrotechnical Commission (IEC) focused on the issue of requirements for computer security programs and system development processes to prevent and/or minimize the impact of cyberattacks against digital instrumentation and control (I&C) systems. It was approved in 2020 as a European Standard as well (EN IEC 62645). The IEC 62859 is a standard, issued at the end of 2016, which coordinates the safety and cybersecurity requirements. With an amendment this standard is also since 2020 a European one (EN IEC 62859). The IEC 63069 adopts all controls from the ISO/IEC 27002 specific for the nuclear field and was issued 2020. Several technical reports (non-prescriptive) complete the standard. IEC TR 63415 on security modeling has been in issued in 2023. IEC TR 63486 was on security risk analysis was started in 2020 and will produce additional guidance on these subjects as relates to the available analysis methods to be used in the cyber security software development and operating cycle. An additional new project on software vulnerabilities (patch management) and end-of-life management was introduced in 2022 and will result in an issued technical specification in the coming years. Perspectives regarding evolution of these standards and development of new ones are provided in the conclusion. These standards define a common international framework, consistent with the IAEA NSS series principles, and within which the evolving country specific requirements can be developed and applied, depending on their own contexts and installations (including SMRs). Such a converged and complete international framework is a key success condition for SMR development. Keywords: Cyber, Software, Digital, Security, Vulnerabilities

# Recent Advancements of Metallic Materials for Integral Molten Salt Reactors

**Speaker: A. S. Alomari [1]**

Primary Authors: Abdullah Alomari [2]; Alaa Milibari [3]; Mohammed Alhazmi [3]

*[1] TBC; [2] King Abdulaziz City for Science and Technology; [3] KACST*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 3: Engineering, Codes & Standards, Supply Chain, Operation and Maintenance of SMRs (A.3)

**INDICO Abstract ID: 305**

**Abstract**

The Integral Molten Salt Reactor (IMSR) is a design for a type of advanced nuclear reactor that utilizes molten salt as both the coolant and the fuel solvent, targeted at developing a commercial product for the small modular reactor (SMR) market. This innovative approach to nuclear reactor design offers several advantages over traditional solid-fueled reactors, including enhanced safety features, improved fuel efficiency, and greater operational flexibility. The status of metallic structural materials for IMSR is an area of active research and development, driven by the unique demands that the molten salt environment places on reactor components. One of the primary concerns with metallic materials in IMSRs is their resistance to corrosion by molten salts. Furthermore, materials used in these reactors must maintain their mechanical integrity, resist creep, and avoid embrittlement under these conditions. High-temperature materials such as nickel-based superalloys and advanced stainless steels are under investigation for their suitability in MSR applications. The materials used in MSRs must also withstand the effects of neutron irradiation, including displacement damage and transmutation. Radiation can alter material properties, leading to swelling, hardening, and embrittlement. In this paper, recent advancements of metallic materials for IMSRs including advanced stainless stees, nickel super alloys and high entropy alloys are thoroughly presented and reviewed in terms of corrosion resistance, high-temperature performance and radiation resistance. Further, testing and standardization for code qualification and regulatory and licensing considerations are also examined.

# Design of a reusable Materials Irradiation DevIce (MIDI) in High Flux Reactor in Petten for testing and qualification of SMR materials

**Speaker: N.j. Barron**

Primary Author: N.v.v.r.m. Kolluri (nuclear Research And Consultancy Group) [1]

Co-Authors: N. Barron [2]; E. D'agata [3]; A. Hamers [2]; O. Martin [3]; F. Naziris [2]; D. Verbruggen [2]

*[1] Nuclear Research and consultancy Group (NRG); [2] NRG, Netherlands; [3] JRC, Petten, The Netherlands*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 3: Engineering, Codes & Standards, Supply Chain, Operation and Maintenance of SMRs (A.3)

**INDICO Abstract ID: 371**

**Abstract**

Irradiation testing of novel and established materials is a crucial step to enable the deployment of SMRs utilizing new materials and/or manufacturing processes to meet hypothetical SMR construction timeframes and realize the complex integrated features of several designs. The High Flux Reactor (HFR) in Petten has played a substantial role in contributing to the irradiation testing of materials and fuels. Several hundred irradiation experiments have been performed over the decades, including the LYRA irradiations. LYRA was a re-usable irradiation facility in the HFR which has been extensively used for irradiation of pressure vessel steels and other structural materials to support LTO-research and qualification of new materials. After its 10th irradiation campaign, the LYRA facility was dismantled and a project begun to replace it that incorporated this multi-year learning. This new, reusable Materials Irradiation DevIce (MIDI) is being designed and developed in collaboration with the Joint Research Centre (JRC) Petten as part of the Dutch government funded PIONEER program. This paper will present the work to-date in developing the engineering design and specifications of the MIDI device, how learning from LYRA has been incorporated, and how the MIDI facility will support the irradiation testing of materials for selected SMR concepts.

# Interactive Graphic Simulator of the CAREM25 Reactor: A Tool for Design Verification and Operator Training

**Speaker: A. Hosid**

Primary Authors: Francisco Alderete Tommasi [1]; Ariel Hosid [1]

Co-Authors: Norberto Abaurre [1]; Alfredo Breitenbücher [1]; Marcelo Castelao Caruana [1]; Andrés Etchepareborda [1]; Fabián Lema [1]; Leonardo Mendieta [1]; Gonzalo Molina [1]; Juan Pablo Pierini [1]

*[1] CNEA*

**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 3: Engineering, Codes & Standards, Supply Chain, Operation and Maintenance of SMRs (A.3)

**INDICO Abstract ID: 397**

## Abstract

This paper presents the Interactive Graphic Simulator (SGI) of the CAREM25 reactor, which is used as a tool for verifying its engineering and design. The development of this SGI is part of the design and development of a Full-Scope Simulator (SAT), which will be used for training operators of the CAREM25 nuclear power plant. The paper describes the models of the systems included in the SGI, along with the graphical user interface, the reactor control configurations, and the tool used for exchanging variables between the different coupled codes involved. It also shows the types of simulations that can be performed with this simulator and the results obtained when performing different transition maneuvers between operating states, emphasizing the procedures and actions carried out to perform these maneuvers. Finally, the paper concludes with the results found and how they are used to support the reactor design. Keywords: CAREM25, SMR, nuclear reactor, simulator, design verification, operator training, transient analysis, safety analysis.

## Track 4: Transportable SMRs (A.4)

# Security Considerations for Floating Nuclear Power Plants when Stationary


**Speaker: R. Peel**

Primary Authors: George Burnett; Ross Peel [1]

*[1] King's College London*


**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 4: Transportable SMRs (A.4)

**INDICO Abstract ID: 384**


**Abstract**

The nuclear industry is currently anticipating the start of a transition within this decade from a technologically narrow set of gigawatt-scale reactors to a much more diverse array of technologies, including many evolutionary and innovative reactor designs. Both the security lessons of the past and today's latest international guidance are being applied to this suite of novel technologies with some success. One particularly unique group of innovative nuclear technologies are floating nuclear power plants – floating platforms which may be moved on water and operated as nuclear power plants to supply energy to consumers. The unique context within which these technologies will exist, operate, and be maintained and refuelled creates the potential for a range of emerging security challenges, in part created by the likely requirement to comply with established maritime law. These include new threat actor groups, intentions, and attack vectors, designed to exploit the unique vulnerabilities of these technologies. The paper details the range of unique physical protection, cyber and insider threat challenges faced by floating nuclear power plants and operators, focusing on those encountered when the plant is stationary during its various lifecycle, as opposed to in transport, when a somewhat different set of considerations would apply. In doing so, it takes a non-technology-specific approach, looking across the range of floating nuclear power plant subtypes. It is recommended that developers consider security as a key design driver from the earliest stages of the design process to address these issues effectively.

# Features of application of IAEA safeguards during refueling of spent fuel on floating power unit for foreign markets with a reactor unit of the RITM type

**Speaker: T. Tagirova**

Primary Authors: Vladimir Malev; Tatiana Tagirova

Co-Authors: Sergey Brykalov [1]; Sergey Dushev [1]; Nadezhda Salnikova [2]

*[1] Afrikantov OKBM JSC; [2] JSC "Afrikantov OKBM"*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 4: Transportable SMRs (A.4)

**INDICO Abstract ID: 119**

**Abstract**

After the successful commissioning of *Akademik Lomonosov* floating power unit with the KLT-40S reactor unit, the next step of ROSATOM was the development of floating power units for foreign markets with the RITM type reactor unit (FPU). The technical solutions of the FPU are based on practical experience in the design and operation of nuclear icebreakers and solving problems to ensure the safety of operation of nuclear power plants in the harsh conditions of the North. The technology of refueling the RITM series reactors has a number of features compared to the technology of refueling other nuclear power plants with water-powered reactors. RITM-type facilities have never been placed under IAEA safeguards, and their application requires additional analysis. Assumed that the FPU will be operated at the operation site for a long period of time, and all fuel handling operations will be carried out at a specialized enterprise in the Russian Federation. The article will consider the main features of fuel management using the example of FPU with the RITM-200M reactor unit from the point of view of IAEA safeguards, and present the developers' vision of nonproliferation tasks regarding technical features of FPU.

# EXPERIENCE OF FLOATING NUCLEAR POWER PLANT (FNPP) OPERATION. TECHNICAL RESULTS ASSESSMENT.

**Speaker: R.a. Beltyukov**

Primary Authors: Roman Beltyukov [1]; Kirill Toropov [1]

*[1] JSC Concern Rosenergoatom*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 4: Transportable SMRs (A.4)

**INDICO Abstract ID: 52**

**Abstract**

Small modular reactors (SMRs) are demanding in many countries in the world. SMRs have a range of advantages with regard to energy supply to remote areas. Russian Federation has unique experience in the implementation of floating nuclear power plant with KLT-40S reactor and advanced land-based modular reactors RITM200. FNPP has a unique design. This small NPP is under operation in severe environmental conditions of the Far North of Russia. Since 2019 to present days, several problems have been identified in operation of FNPP equipment and systems. Structural and design deficiencies have been analyzed. Then relevant action plans have been developed and implemented in the following areas: • replacement of defective internals of steam generators of FNPP; • handling of fresh nuclear fuel; • elimination of constructive and design deficiencies of some FNPP equipment; • spent nuclear fuel handling; • preparation for FNPP repair at the place of permanent basing without interruption of electrical and steam generation • optimization of transport and technical ways of removing solid radioactive waste and liquid radioactive waste. The results of the analysis of the FNPP operating experience are used to identify future directions of development as follows: 1. New core development with an increased power capacity and a longer duration of the fuel campaign. 2. Implementation of a modernized steam generator with straight-tube design to increase its reliability.

# Risk-based Technology Qualification to address the marinization of SMRs

**Speaker: J. Esteve Otegui**

Primary Author: Jose Esteve Otegui [1]

*[1] Bureau Veritas*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 4: Transportable SMRs (A.4)

**INDICO Abstract ID: 107**

## Abstract

One of the proposed advantages of small modular reactors (SMRs) is that they could be built in controlled factory environments and transported to power plant sites for installation. This concept aligns with the nascent ideas of transportable nuclear power plants (TNPPs) and floating nuclear power plants (FNPPs) that could be constructed in shipyards specialized in building large, complex vessels. The proposition is that a maximum of components outside the SMR itself are built by the yard and its supply chain, using as much as possible the existing codes and standards that such industry is used to apply, from the marine and the offshore oil & gas sectors. The author will present a risk-based technology qualification approach demonstrated with floating liquefied natural gas projects 10-15 years ago. This methodological approach helps with the process of identifying those components that will be designed, built, installed, operated, maintained and decommissioned considering a different environment, codes, and supply chains to those of the nuclear industry and then assessing the technology qualification activities that will be needed. The goal is to provide a methodology that can help realize the promised deployment potential of SMRs through non-traditional construction and siting approaches.

# Shielding Systems for Nuclear System of Maritime SMR


**Speaker: J. Kim**

Primary Author: Jinho Kim (hd Korea Shipbuilding & Offshore Engineering Co., Ltd.) [1]

Co-Authors: Sungkon Han (hd Korea Shipbuilding & Offshore Engineering Co., Ltd.) [1]; Byeongju Kim (hd Korea Shipbuilding & Offshore Engineering Co., Ltd.) [1]; Taewoo Kim (hd Korea Shipbuilding & Offshore Engineering Co., Ltd.) [1]; Jekyoung Lee (hd Korea Shipbuilding & Offshore Engineering Co., Ltd.) [1]; Jeonghyeon Lee (hd Korea Shipbuilding & Offshore Engineering Co., Ltd.) [1]; Byeonghyeon Min (hd Korea Shipbuilding & Offshore Engineering Co., Ltd.) [1]; Dongbin Park (hd Korea Shipbuilding & Offshore Engineering Co., Ltd.) [1]; Sangmin Park (hd Korea Shipbuilding & Offshore Engineering Co., Ltd.) [1]; Yeobum Youn (hd Korea Shipbuilding & Offshore Engineering Co., Ltd.) [1]

*[1] HD Korea Shipbuilding & Offshore Engineering Co., Ltd. (HD KSOE)*



**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 4: Transportable SMRs (A.4)

**INDICO Abstract ID: 156**


## Abstract


Maritime Small Modular Reactor (SMR) products, such as Nuclear Propulsion Ships (NPS) and Floating Nuclear Power Plants (FNPP) have been emerging as a game changer in the shipbuilding and offshore industry. Success of the maritime SMR development highly relies on the shielding systems, which are to be designed to accommodate constraints for maritime applications. In the development the land based concrete shielding system will be replaced with a viable alternative to be installed inside the vessels, which secure crews a safe working environment. In addition to the shielding systems, it is crucial in the marine application to efficiently arrange complex nuclear reactor systems including the primary and secondary systems within the limited space. A new operation philosophy will be developed to overcome the space limits. The present paper will address how the land based nuclear power plant system can be designed and arranged inside the marine vessels. Additionally, we suggest shielding systems based on the arrangement of nuclear reactor systems that complies with annual radiation exposure limits. The design of these systems primarily focus on replacing the concrete

structures of land based nuclear reactors within the limited space of NPS and FNPP, with effective shielding against gamma rays and neutrons.

# Classification Requirements for Floating Nuclear Power Plants (FNPPs)


**Speaker: M. Dowling**

Primary Author: Meg Dowling [1]

Co-Authors: Derek Novak [1]; Jin Wang [1]

*[1] American Bureau of Shipping*


**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 4: Transportable SMRs (A.4)

**INDICO Abstract ID: 185**


**Abstract**

Increased interest in advanced nuclear technology for global decarbonization includes commercial floating nuclear power plants (FNPPs). Like all vessels today, FNPPs will be registered to a Flag State, which usually delegates some responsibility to Classification Societies, such as the American Bureau of Shipping (ABS), to perform engineering reviews, inspections and surveys on their behalf. The role of Classification is explained to provide an understanding of the marine regulatory framework and the integration with nuclear regulatory regimes. Existing International Maritime Organization (IMO) regulations apply to nuclear merchant ships using pressurized water reactors but may not directly apply to FNPPs. To support the technology-agnostic production of FNPPs, the ABS Requirements for Nuclear Power Systems for Marine and Offshore Applications provide minimum requirements to obtain the **Power Service (Nuclear)** Classification Notation. The provisions for Classification using these requirements are described, including the risk assessment, Interface Document, integration testing and in-service survey plans that are required to differentiate the verification activities of Classification from the nuclear regulator for design and license approvals. These requirements may be used for FNPPs and leveraged later for nuclear ships, to guide the collaboration of the maritime and nuclear industries for successful implementation of commercial nuclear-maritime applications.

# 3S APPROACH TO BRING NUCLEAR ENERGY TO WHERE IT'S NEEDED


**Speaker: F. Puente-espel**

Primary Author: Federico Puente-espel [1]

Co-Authors: Mathias Trojer [1]; Marcel Devos [1]

*[1] Prodigy Clean Energy*


**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 4: Transportable SMRs (A.4)

**INDICO Abstract ID: 195**


**Abstract**

Nuclear energy has the potential to substantially help resolve the three biggest energy challenges faced today: mitigating both climate change and energy poverty while bringing greater energy security to where the energy is actually needed. Small Modular Reactors as well as Microreactors extend the applications of conventional large nuclear power plants to electric and non-electric, present new deployment models, intend to have shorter construction times, lower capital costs, served as the perfect combination for a sustainable power mix supporting renewables as a baseload and/or load following, and advanced technologies include safety, security, and safeguards by design (3S). One of the most attractive concepts of SMRs & MR is the possibility of being transported to places where energy is needed, remote places and industrial sites for example. Prodigy is developing nuclear oversight and quality assurance models for shipyard fabrication, transport, fuel handling and decommissioning to support sustainable project execution. The paper presents a strategy for successful emergence of Transportable and marine-deployed nuclear power based on realistic and highly replicable technologies, licensable under current regimes, that can meet immediate commercial need with market entry achievable in the short term needed. Several examples are illustrated; for SMR and Microreactor, for several sites, and to replaced coastal fossil fired generation.

# Evaluation of the Molten Salt Reactor technology for the application of Floating Nuclear Power Plants

**Speaker: I. Kourasis**

Primary Author: Ioannis Kourasis [1]

Co-Authors: Scott Edwards [1]; Oscar Hamilton [1]; Phil Malone [1]; Jake Miles [1]; Mamdouh El-shanawany [1]

*[1] Core Power*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 4: Transportable SMRs (A.4)

**INDICO Abstract ID: 233**

**Abstract**

Floating Nuclear Power Plants (FNPP) present a promising pathway to broaden the acceptance of nuclear power by addressing critical challenges faced by land-based reactors, including high capital expenditures (CAPEX), prolonged construction timelines, and societal resistance. This paper provides a thorough assessment of the applicability of liquid-fueled Molten Salt Reactors (MSRs) within marine applications. It specifically delivers a comprehensive examination of the current MSR designs under development, evaluating their design attributes and capabilities in the context of the marine environment and the operational profile of floating platforms. Additionally, the research investigates the potential fuel cycles, focusing on the innovative approaches to refueling liquid fuel reactors. The paper is aimed at enhancing the overall understanding of advanced reactors suitability for marine deployment, paving the way for a more cost-effective and easily deployable nuclear power solution.

# Deployment and uses of Floating Nuclear Power Plants powered by Small Modular Reactors

**Speaker: W.s. Edwards**

Primary Author: Scott Edwards [1]

Co-Authors: Bright Ahonsi [1]; Thomas Davies [1]; Rory Megginson [1]

*[1] Core Power*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 4: Transportable SMRs (A.4)

**INDICO Abstract ID: 235**

**Abstract**

Floating Nuclear Power Plants (FNPPs) emerge as a pivotal solution for swiftly deploying additional power generation capacity in a cost-effective and scalable manner. Particularly suited for coastal regions facing energy access challenges or where the construction of terrestrial nuclear power facilities is impractical, FNPPs offer a versatile and innovative approach to energy provision. This paper delves into the technical strategies for integrating Small Modular Reactors (SMRs) into these marine platforms, featuring qualitative analyses of various hull designs to ascertain the most effective configurations. Moreover, it presents a comprehensive exploration of the multifaceted applications of SMRs within FNPPs, including their role in powering desalination plants and the production of e-fuels. This examination underscores the transformative potential of FNPPs in addressing global energy needs, highlighting their flexibility, efficiency, and broad utility in supporting sustainable development goals.

# Reactor Plants for Nuclear Ships and Floating Nuclear Power Plants. Development Experience and Improvement Prospects.

**Speaker: K.b. Veshnyakov**

Primary Authors: Pavel Gorbunov [1]; Alexei Pakhomov [1]; Alexander Turusov [1]; Konstantin Veshnyakov [1]

*[1] Afrikantov OKBM, JSC*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 4: Transportable SMRs (A.4)

**INDICO Abstract ID: 244**

**Abstract**

One of the most effective ways to ensure logistics and economic activities in the Arctic region is to use nuclear-powered icebreakers having a high icebreaking capability and navigation autonomy. From 1959 and to this day, four generations of reactor plants for nuclear ships and floating power units (FPUs) have been developed and tested under real operating conditions. Twenty-eight reactor plants have been providing reliable operation of twelve nuclear ships and the FPU Akademik Lomonosov under Arctic conditions, and there are plans to commission thirty more reactor plants on fifteen ships and FPUs in the future. The operating experience with nuclear ships and the FPU Akademik Lomonosov has confirmed that the technical policy is correct and promising. Starting with the reactor plants for the world's first nuclear-powered icebreaker, the reactor technology and safety of nuclear ships and FPU have been continuously improving. A special focus is on the safety of reactor plants. The safety measures include both reactor plant inherent safety and a whole set of active and passive safety systems. The said systems are designed for all types of design-basis accidents, including a blackout, and they also ensure sufficient time margin in beyond-design-basis scenarios. Being compact in size, the marine reactor plants have a high level of safety and reasonable economic efficiency, which enabled developing a fundamentally new class of energy sources—FPUs. The energy sources of this type are capable of generating energy in remote and hard-to-reach regions without requiring regular fuel supplies. The developed energy sources are universal and capable of operating in both

50 Hz and 60 Hz AC power grids, which allows the electricity needs of any consumer to be met.

# Enabling versatile nuclear deployments of the eVinci microreactor


**Speaker: A. Spalding [1]**

Primary Author: Agata Leszkiewicz [2]

*[1] TBC; [2] Westinghouse Electric*


**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 4: Transportable SMRs (A.4)

**INDICO Abstract ID: 333**


**Abstract**

Westinghouse is developing the eVinci microreactor, a 5MWe, 15MWth microreactor with the intention of having the most versatile and flexible microreactor on the market. The reactor will to be factory built and deployed fully fueled to the site, transported by rail, road or barge. Westinghouse is also investigating deployment through a TNPP together with their partnership with Prodigy Energy. The discussion will present various aspects of the design which enable a transportable size and weight including utilization of TRISO fuel, heat pipes and open air Brayton power conversion system. In addition, it contains various passive safety features which facilitate deployment and operation in remote locations which requiring minimal personnel for monitoring, maintenance or operations. These design features are also coupled with a simplified site layout requiring limited construction, above ground installation and return back to greenfield. The discussion will also discuss the challenges from a social and regulatory pathway which will need to be overcome to allow for a novel way of deployment for microreactors, in order to enable a green-energy transition for remote and hard to reach locations.

# Floating Nuclear Power Plants: Legal and Regulatory Gap Analysis

**Speaker: H. Raza**

Primary Author: Hamid Raza

Co-Authors: Noreen Iftakhar (pakistan Nuclear Regulatory Authority) [1]; Muhammad Abid Aslam Meo (pakistan Nuclear Regulatory Authority) [1]; Jan Muhammad (pakistan Nuclear Regulatory Authority) [1]

*[1] Pakistan Nuclear Regulatory Authority (PNRA)*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 4: Transportable SMRs (A.4)

**INDICO Abstract ID: 361**

**Abstract**

Floating Nuclear Power Plants (FNPPs) present a novel approach to install small modular reactors (SMRs) on floating barges or platforms to provide clean electricity and heat for remote coastal locations, to decarbonize offshore oil and gas or mining activities, or even to provide grid scale electricity production. Their mobility offers advantages over traditional land-based plants, but also pose unique transport-related legal and regulatory challenges. The international legal and regulatory framework for the peaceful use of nuclear energy has evolved over time to govern the diverse applications of nuclear technology and achieve nuclear safety worldwide. However, specific requirements for floating reactors are still missing in the legal instruments governing nuclear safety. For example, the Convention on Nuclear Safety (CNS) primarily addresses only land-based facilities. On the other hand, deficiencies also exist in the legal regime of maritime safety regarding the definition of FNPPs as nuclear ships. In addition, there is a need to evaluate the existing IAEA safety standards for nuclear installations such as SSR 2/1 GSR Part 4, and SSR-6 in the light of peculiar safety aspects of FNPPs. This paper will highlight the gaps in the existing international nuclear safety regime with regard to FNPPs. Based on the gap analysis, the paper aims to contribute to the safe and responsible deployment of FNPPs, facilitating their potential as a clean energy source.

# The Activities of INPRO in Transportable Nuclear Power Plants


**Speaker: A. Bychkov, G. Sayin**

Primary Authors: Alexander Bychkov [1]; Gaye Sayin

*[1] Private*


**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 4: Transportable SMRs (A.4)

**INDICO Abstract ID: 368**


**Abstract**

The International Atomic Energy Agency (IAEA) through it's forward-looking International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) assists Member States (MSs) in formulating comprehensive long-term strategies for implementation of sustainable nuclear energy. INPRO has several activities related to the deployment of transportable small modular reactors (SMRs). The first activity, completed in 2012, focused on legal, institutional, and ownership-related challenges associated with deploying TNPPs, analysed various technological options and deployment scenarios, identified challenges, and assessed the impact on recipient countries' infrastructure. This activity explored two technical options for TNPPs. Option 1: involved a preassembled TNPP with fuelling, testing, maintenance, and decommissioning done at the supplier's factory. Option 2: was a preassembled TNPP with non-nuclear testing done at the factory, and maintenance, fuelling, and refuelling done on site. A second study, begun in 2015, delved deeper into some of the issues from Option 1, identifying gaps and providing more detailed analysis of legal and institutional challenges related to TNPP deployment. In November 2023, INPRO in collaboration with other departments, held a symposium on Floating Nuclear Power Plants (FNPPs), which brought together international experts and organizations to discuss the challenges of deploying sustainably FNPPs.

# CHALLENGES IN THE HARMONISATION OF LEGAL INSTRUMENTS ON 3S (SAFETY, SECURITY, SAFEGUARDS) AND CIVIL LIABILITY FOR MARINE- NUCLEAR SYSTEMS BETWEEN THE INTERNATIONAL ATOMIC ENERGY AGENCY AND THE INTERNATIONAL MARITIME ORGANISATION


**Speaker: J.s. Choi**

Primary Author: Jor-shan Choi (lawrence Livermore National Laboratory) [1]

*[1] Lawrence Livermore National Laboratory (retired)*


**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 4: Transportable SMRs (A.4)

**INDICO Abstract ID: 103**


**Abstract**

Global shipping uses ~300 million t of fossil fuels annually, producing 3% of CO2 emissions. In July 2023, the IMO set a net-zero emissions goal for 2050 (100% reduction by 2050 comparing to 2008 level). Supporting this goal, the maritime industry is pursuing deep decarbonization with nuclear ships, which is a ship provided with a SMR. Today, some 200 nuclear reactors are operating on 160 vessels, mostly naval ships, icebreakers, and submarines. The interests in FNPPs have grown since Russia deployed the Akademik Lomonosov with 2 SMRs on board in 2020, and the interests in nuclear ships have also grown since the IMO mandate on decarbonization. However, nuclear ships could pose risks in the events of reactor accidents, terrorists attacks, or proliferation threats, and the current legal instruments governing 3S (safety, security, and safeguards) and civil liability for nuclear ships are not sufficient to address these risks. Hence, the challenges in applying these legal instruments for nuclear ships include: • The Convention on Nuclear Safety (CNS) is currently not applicable to nuclear ships. • The nuclear-security instruments by IAEA focus on transport of nuclear and radioactive materials. And transport-security instruments by IMO need to extend to include nuclear ships. There is also a need to harmonize these two sets of security instruments for clarity and consistency. • The safeguards of many non-water-based SMRs intended for nuclear ships by non-nuclear-weapons countries are not yet

developed. • Current Conventions on civil liability for nuclear damage may not be applicable to damages a nuclear ship incurred in attack by non-state actors in open sea. This study addresses the 3S-and-civil-liability legal instruments of the IAEA and the IMO for marine-nuclear systems, with focus on the harmonization of these instruments between the two.

# Implementation of projects of nuclear floating power units within the framework of maritime and nuclear law and approaches to regulation

**Speaker: V. Malev**

Primary Authors: Vladimir Aptekarev [1]; Daria Sabusova [2]

Co-Authors: Sergey Brykalov [2]; Nadezhda Salnikova [3]

*[1] JSC "Atomenergomash"; [2] Afrikantov OKBM JSC; [3] JSC "Afrikantov OKBM"*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 4: Transportable SMRs (A.4)

**INDICO Abstract ID: 118**

**Abstract**

The world is facing growing global energy demands and the need to reduce reliance on non-ecological energy sources. Floating nuclear power units can serve as a flexible and sustainable option for generating power. The identification of FNPUs as nuclear vessels and facilities underlines the need for adherence to international regulations of both the nuclear and maritime law, because the deployment of FNPUs presents unique challenges in terms of safety and optimal regulatory approach. There are no specific nuclear safety regulations for FNPUs in the maritime and nuclear law, moreover the standard scenario for licensing stationary nuclear power plants is not applicable to FNPUs. Operating different types of nuclear vessels, including the FOAK FNPU *Akademik Lomonosov*, has provided the unique operation experience. FNPUs comply with safety and regulatory requirements for nuclear vessels, except for those specific to the nuclear power unit, except the distinction that FNPUs are non-self-propelled. The IAEA GSRs and SSRs seem also to be applicable in general. In the future when more FNPUs operation experience is gained it would be possible to develop special nuclear safety requirements and to adapt the practices of regulating nuclear vessels in relation to FNPUs.

## Track 5: Non-Electric Applications for SMR (A.5)

# NUWARD SMR cogeneration services

**Speaker: C. Terrier**

Primary Authors: Cedric Terrier [1]; Alexandra Menges; Jean-françois Dhedin

*[1] NUWARD*

**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 5: Non-Electric Applications for SMR (A.5)

**INDICO Abstract ID: 243**

### Abstract

Since the creation of the French nuclear fleet, the question of adding a cogeneration option (also known as Combined Heat and Power CHP) has arisen in connection with the different crises on the price of fossil fuels. Leveraging the direct utilization of nuclear heat for industrial applications emerges as a compelling alternative to relying on fossil fuels, showcasing superior efficiency compared to generating heat through electricity. Given Europe's current objective to decarbonize energy consumption, the CHP appears to be an interesting option for the new generation of Nuclear Power Plants (NPPs), especially for Small Modular Reactors (SMRs) and is part of NUWARD SMR features. The pressure/temperature characteristics of NUWARD SMR are suitable for supplying a range of industrial applications such as hydrogen production with high temperature electrolysis, desalination, district heating, industrial heating or direct air capture. Besides they are easier to build and can be placed close to industrial or urban areas where needs are. Depending on the specific industrial application, the steam extraction location can be adapted to find a compromise between electricity production and the required steam characteristics. Integrating the CHP options also requires design specific analyses: hazard assessments, operating impact, plot plan integration and design of new equipment such as steam transformers. These development and analyses ensure a seamless integration and operation of CHP systems, as a service provided by NUWARD SMR.

# Simulation of flexible Small Modular Reactor operation with a thermal energy storage system

**Speaker: G. Masotti**

Primary Authors: Guido Masotti [1]; Nicolas Alpy [2]; Stefano Lorenzi [1]; Marco Ricotti [1]; Giorgio Simonini [3]

*[1] Politecnico di Milano; [2] CEA; [3] EDF*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 5: Non-Electric Applications for SMR (A.5)

**INDICO Abstract ID: 307**

**Abstract**

The surging penetration of variable renewable energy sources into power grids translates into an urgent need for dispatchable generators such as nuclear power plants to effectively balance grid demand. However, nuclear reactors have been traditionally operated as baseload power sources, leveraging the technical and economic advantages of this operational mode. This paper explores the integration of a two-tank thermal energy storage (TES) system with a light-water cooled Small Modular Reactor (SMR) as an alternative to address the flexibility requirements and, at the same time, minimise thermal power variation in the nuclear steam supply system. In this work, the dynamics of the coupled SMR-TES system are examined across various scenarios by means of dynamic models developed in the object-oriented modelling language Modelica. The aim is to analyse the potential impact of a TES on the operational strategies of a SMR in the context of highly fluctuating load demands. Through this investigation, the study aims at demonstrating that nuclear energy systems can satisfy the evolving grid requirements with minimal perturbations on the nuclear reactor's operation. The results show that the SMR is able to meet variable load demands by exchanging power with the TES, ensuring reliable energy supply.

# Stakeholder Perspectives on Challenges in Integrating and Developing Infrastructure for Small Modular Reactors (SMRs) in Kuwait

**Speaker: S. Alsanad**

Primary Author: Dr.shaikha Alsanad [1]

Co-Authors: Bader Almutairi [1]; Hussain Albaghli [1]

*[1] Kuwait Institute for Scientific Research*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 5: Non-Electric Applications for SMR (A.5)

**INDICO Abstract ID: 271**

## Abstract

Kuwait endeavors to reduce its reliance on oil in alignment with the Kuwait National Development Plan, diverting investments towards non-oil sectors. Concurrently, the nation is committed to mitigating greenhouse gas emissions. Recognizing the nuclear energy chain as a highly dependable and low-emission power source per unit, Kuwait deems it imperative to incorporate various low-carbon energy technologies, particularly nuclear power, to meet its climate policy objectives. Small Modular Reactors (SMRs) emerge as promising contributors to climate change mitigation and bolstering energy security. This study, an integral part of an ongoing research initiative, delves into the challenges associated with integrating and developing Small Modular Reactor (SMR) infrastructure in Kuwait, encompassing diverse stakeholder perspectives. Employing an empirical-qualitative approach, incorporating expert interviews and discussions, the research explores hurdles in nuclear infrastructure development, addressing regulatory frameworks, technical considerations, and the necessity for capacity-building. Notably, local political instability emerges as a significant risk, according to the majority of interviewed experts, directly influencing the development of a national nuclear program. This instability contributes to a lack of governance within various institutions across the country, posing both direct and indirect risks to the nuclear program's progress. The paper strives to provide decision-makers with a comprehensive understanding of these challenges for informed decision-making.

# Why SMRs are crucial for hard-to-abate sectors such as shipping and what to do about it

**Speaker: J. Emblemsvåg**

Primary Authors: Jan Emblemsvåg [1]; César Hueso Ordóñez [2]; Terje Strand [1]; Cristian Garrido Tamm [2]; Helge Thoresen [1]; Javier Santos Ortigosa [2]; Alejandria Perez [3]; Yolanda Mugica Colilles [2]

*[1] Norwegian University of Science and Technology; [2] IDOM; [3] KTH Royal Institute of Technology*

**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 5: Non-Electric Applications for SMR (A.5)

**INDICO Abstract ID: 18**

**Abstract**

The marine industry consumes about 300 million tonnes Heavy Fuel Oil (HFO) annually (Jacoby 2022), emitting 3% of total global climate gas emissions (King 2022). Worse, the emissions are expected to grow to more than 10%. Then, add local- and regional shipping using marine diesel oil. Currently, green ammonia is the focal point as a possible alternative to HFO to decarbonize shipping (King 2022). Yet, the amount of electricity required to produce the equivalent amount of green ammonia is about 7,800 TWh/yr, or more than 2.7 times the total EU electricity production in 2022 (Emblemsvåg 2024). The light water reactors have historically demonstrated that they are too costly for this purpose, so here we present the Generation IV SMR technologies that have the potential to commercially enable zero-emission shipping. Indeed, some Generation IV SMRs may outcompete HFO on costs (Emblemsvåg 2021). The paper will end by discussing the challenges to solve. References Emblemsvåg, J. (2021). "How Thorium-based Molten Salt Reactor can provide clean, safe and cost-effective technology for deep-sea shipping." Marine Technology Socieity Journal55(1):pp.56-72. Emblemsvåg, J. (2024). Electricity is Easy – Fuels are Hard: Lessons from the Maritime Industry. Handbook of Power Systems. M. Freunek and O. Doleski: Accepted for publication. Jacoby, M. (2022). The shipping industry looks for green fuels.Chemical & Engineering News, American Chemical Society.100: https://cen.acs.org/environment/greenhouse-gases/shipping-industry-looks-green-fuels/100/i108. King, A. (2022). Emissions-free sailing is full steam ahead for ocean-going shipping. Horizon - the EU Research &

Innovation Magazine, European Commission. https://ec.europa.eu/research-and-innovation/en/horizon-magazine/emissions-free-sailing-full-steam-ahead-ocean-going-shipping.

# Electricity and Water cogeneration using a Small 75MWth PWR

**Speaker: M. De Lourdes Moreira**

Primary Author: Paulo Augusto Berquó De Sampaio [1]

Co-Authors: Maria Moreira [1]; Luiz Flávio Rodrigues Alves [2]

*[1] Comissão Nacional de Energia Nuclear; [2] Eletronuclear*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 5: Non-Electric Applications for SMR (A.5)

**INDICO Abstract ID: 28**

**Abstract**

This paper investigates a hybrid desalination strategy, using both Direct Contact Membrane Distillation (DCMD) and Sea Water Reverse Osmosis (SWRO), for cogeneration of water and electricity using a small PWR of 75 MW(th). Blending the water produced by SWRO with that produced by DCMD has two main advantages. One is the improvement of the quality of the water produced, as compared to that obtained with the SWRO plant. The other is the reduction of the cost of water production, as compared to that attained by the DCMD plant alone. The SWRO plant uses the electricity generated on site by the small PWR. The water production of the SWRO plant is determined using the electricity consumption of 4 kW(e)h per cubic meter, which is a value typical of a real-scale SWRO plant. On the other hand, we divide the steam produced in the steam generator into two parallel Rankine cycles. The first of those cycles operates at pressures and temperatures typical of a Rankine cycle optimized for electricity generation. In the second cycle, steam expansion in the turbine is shortened to a pressure just below the atmospheric pressure. Thus, steam condensation occurs at a temperature just below 100 ºC, which allows heating the seawater in the second Rankine cycle condenser up to 92 ºC. The external heating required for the DCMD desalination process comes exclusively from cooling the two Rankine cycle condensers. So, a specific electricity consumption of 8.47 kW(e)h per cubic meter has been obtained for the DCMD process. These computations used the DE-TOP program, developed by the IAEA, which simulates the Rankine cycles of PWRs, and the DESAL-PLANT program, developed at IEN/CNEN, which models a DCMD desalination plant with heat recovery.

Finally, estimates of water and electricity production are presented, considering the mean seawater temperature of the Brazilian northeast.

# Poly-generation of power and desalinated water by Small Modular Reactors

**Speaker: M. Cioffi**

Primary Author: Marco Cioffi [1]

*[1] Ansaldo Energia*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 5: Non-Electric Applications for SMR (A.5)

**INDICO Abstract ID: 54**

**Abstract**

The request for drinkable and industrial-use water is steadily increasing by following the fast development and urbanization in areas such as the Middle East and by the effect of climate change. The nuclear energy has been even recently confirmed to be one of the key technologies required for the fulfillment of the Energy Transition targets. The Small Modular Reactor concept is often coupled with the hybridization of Nuclear Power Plants with other services, such as the concurrent generation of Power with Heat, Hydrogen, or Water. This approach has the additional purpose of providing flexibility on the NPP operation in a power grid influenced by not-programmable renewable energy sources. One of the most promising uses of SMR is the desalinization of seawater for agriculture, industrial or civil use. The desalination technology should fit with the inlet water characteristics and output water requirements (Inverse Osmosis, Multi-Stage Flash distillation) by utilizing SMR power and/or heat. This paper presents a technical-economic analysis for the supply of water for the Abu Dhabi city. The analyzed 340 MW SMR plant, hybridized with an inverse osmosis desalination system, is able to provide 1,000,000 m3/day of drinkable water, almost 1/3 of the water daily used by the city.

# IDNES a CEA projet dedicated to SMR concept for decarbonization beyond pure power generation


**Speaker: P. Amphoux**

Primary Author: Philippe Amphoux [1]

Co-Authors: Nicolas Alpy [1]; Fabrice Bentivoglio [1]; Luc Bertier [1]; Charly Boudot [1]; Jean-baptiste Droin [1]; Frédéric Ducros [1]; Pierre Gavoille [1]; Eric Hanus [1]; David Haubensack [1]; Clément Liegeard [1]; Franck Morin [1]; Coralie Quadri [1]; Jean-michel Ruggieri [1]; Nicolas Tauveron [1]; Claire Vaglio-gaudard [1]

*[1] CEA*


**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 5: Non-Electric Applications for SMR (A.5)

**INDICO Abstract ID: 79**


**Abstract**

Launched in 2020 within the French Alternatives energies and Atomic Energy Commission (CEA), the IDNES (Innovative Decarbonized Nuclear Energy Systems) project aims to take a new approach to the use of civil nuclear power generation, expanding its role beyond power production to provide other energy carriers by developing energy system concepts that include Small Modula Reactor (SMR) technology. After a first phase of the project, the development and study status are presented in this paper. The work program was initially designed with a 15-year vision aligned with the carbon-neutrality objective by 2050. It has focused primarily on energy markets where decarbonization is a major challenge. This work has identified two markets to be potentially addressed by SMR technology: heat and hydrogen, that can be produced by cogeneration. After an introduction of the methodology used to draw up technical specifications for new markets to be decarbonized, the main configuration of the different concepts developed in the project are explained: - pure heating SMR ARCHEOS concept, - coupled system between SMRs and High Temperature Steam Electrolyzers (HTSE) for hydrogen production and kerosene synthesis, - SMR coupled with massive heat storage for industry supply. Lastly, industrial prospects will be presented.

# Challenges in development of cogeneration module for SMRs

**Speaker: P. Gilski**

Primary Author: Pawel Gilski [1]

*[1] Orlen Synthos Green Energy*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 5: Non-Electric Applications for SMR (A.5)

**INDICO Abstract ID: 95**

**Abstract**

Orlen Synthos Green Energy (OSGE) is a Polish company that plans to deploy a fleet of SMRs in Poland with use of BWRX-300 technology by GE Hitachi Nuclear Energy (GEH). BWRX-300 is designed to produce only electricity, whereas, the waste heat is discharged to the atmosphere via cooling towers, as most of existing large-scale nuclear power plants do. However, the waste heat could be used to supply district heating networks (DHNs) and industrial facilities, therefore making the SMR a cogeneration plant. Cogeneration is widely applied in Poland for coal and gas fired plants, however it is a niche area for the nuclear industry. OSGE believes that nuclear technology is a key solution for decarbonizing the Polish and European energy sector and nuclear cogeneration can only enhance its effect. What is more, cogeneration SMR could be used in wider range of applications than large-scale nuclear cogeneration. This paper is dedicated to describing the challenges in developing the cogeneration module for existing SMR technology in international environment in technical, business and regulatory areas.

# Comparison between a Small Modular Reactor and a traditional nuclear reactor in water desalination cogeneration application

**Speaker: M. Kandil**

Primary Author: Magy Kandil [1]

*[1] Egyptian Atomic Energy Authority, EAEA,Cairo, Egypt*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 5: Non-Electric Applications for SMR (A.5)

**INDICO Abstract ID: 109**

## Abstract

Cogeneration applications of nuclear energy could present sustainable solutions for several energy challenges current and future generations will have to face. There is growing interest around the world in using nuclear energy for cogeneration applications such as seawater desalination, hydrogen production, district heating, and various industrial applications. Small modular reactors represent a key area of interest to nuclear industry developers, which have been making significant progress during the past few years. Generally, these reactors are promising owing to their improved safety due to passive systems, enhanced containment efficiency, and fewer capital costs in comparison to traditional nuclear reactors. The worldwide demand for potable water has been steadily growing and is projected to accelerate while natural reserves of fresh water are generally flat or diminishing. Desalination of seawater is expected to make up the difference; however, the desalination of water is energy intensive, requiring large amounts of electricity and/or thermal energy. Nuclear energy is an attractive option for large scale desalination application since the thermal energy produced in a nuclear plant can provide both electricity and heat for clean water production without the emission of greenhouse gases or the variability of renewable sources. A particularly attractive option for nuclear desalination is to couple a desalination plant with a new generation of designs, small modular reactors. In this research, a comparison between a Small Modular Reactor and a traditional nuclear reactor in water desalination cogeneration application is represented. The NuScale small modular reactor design is especially well suited for the cogeneration of electricity and clean water because of the enhanced

safety, improved affordability, and deployment flexibilities of the plant design, which provides a cost-effective approach to expand a global desalination capacity, so it is compared with a pressurized water reactor. through evaluate the technical and economic considerations of coupling a NuScale plant.

# COGENERATION EMPLOYING THE CAREM MODULAR REACTOR FOR THE PYROLYSIS TREATMENT OF CUTTINGS DERIVED FROM THE OIL AND GAS INDUSTRY IN THE NEUQUÉN BASIN.

**Speaker: G. Fouga**

Primary Author: Gastã³n Fouga [1]

*[1] Bariloche Atomic Center/ National Atomic Energy Commission/National Council of Scientific and Technical Research*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 5: Non-Electric Applications for SMR (A.5)

**INDICO Abstract ID: 127**

**Abstract**

The Physicochemical and Quality Control Department of the Argentina National Atomic Energy Commission has been actively researching the application of the modular CAREM nuclear reactor for cogeneration, specifically for the treatment of oil-based drill cuttings (OBDC) generated from oil and gas extraction in the Neuquén basin, located in the province of Neuquén, Argentina. These cuttings are classified as hazardous waste under National Law 24051. The objective is to utilize cogeneration to supply heat for the pyrolysis process of the cuttings. This process aims to produce a residue suitable for safe disposal and, concurrently, liquid and gaseous fuels that enhance the intrinsic value of the initial waste. In the initial phase of the study, samples of OBDC from the Neuquén Basin were employed, collected at depths of 800 m (OBDC-1), 1100 m (OBDC-2), and 1300 m (OBDC-3). The oil content within the cuttings was quantified using Soxhlet extraction (EPA9071B), while the water content was determined through azeotropic distillation using the Dean-Stark method (ASTM-D95). To investigate the thermal decomposition process and the associated energy, a simultaneous thermal analyzer (DTA-TG, STA-409, NETZSCH) was utilized. Furthermore, the mineralogical composition of the remaining residues was scrutinized employing X-ray diffraction.

# Assessing Viability of Small Modular Reactors in Pakistan’s Energy Landscape: Navigating Technological Diversity and Challenges in Possible Integration with Renewables

**Speaker: H. Ur Rehman**

Primary Author: Haseeb Ur Rehman [1]

Co-Authors: Farhana Kausar (pakistan Atomic Energy Commission) [2]; Aman Ur Rehman [1]; Waqar Riaz [1]

*[1] Pakistan Institute of Engineering and Applied Sciences; [2] Pakistan Atomic Energy Commission (PAEC)*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 5: Non-Electric Applications for SMR (A.5)

**INDICO Abstract ID: 131**

**Abstract**

This paper explores the strategic future design, development, and deployment of Small Modular Reactors (SMRs) in Pakistan, considering the unique challenges and opportunities presented by the country's energy landscape. Using the rigorous International Atomic Energy Agency’s (IAEA) Reactor Technology Assessment (RTA) methodology, a comprehensive analysis is conducted to propose a specific SMR design technology line (i.e., water-cooled reactors, gas-cooled reactors, molten salt reactors, and liquid metal-cooled reactors). The analysis is rooted on expert considerations of 10 key elements and corresponding key topics as a sub-category of each key element of RTA methodology. Furthermore, the assessment also includes an explicit investigation of the potential applications of SMRs in both electricity generation and diverse non-electric contexts within a nuclear-renewable hybrid energy system. The study is aimed to provide a preliminary sketch to the policy makers in pursuing a specific SMR design for the future deployment.

# Nuclear Hydrogen Production Analysis for GT-HTR using HEEP Software


**Speaker: W. Dridi**

Primary Author: Walid Dridi [1]

*[1] Centre National des Sciences et Technologies Nucléaires*


**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 5: Non-Electric Applications for SMR (A.5)

**INDICO Abstract ID: 161**


**Abstract**

Hydrogen demand is expected to sharply increase shortly as technology development uses hydrogen as a new energy source. Currently hydrogen production relies primarily on fossil fuels, which are neither environmentally friendly nor economically efficient. In order to establish a hydrogen economy, it is imperative to produce a large amount of hydrogen in a clean, safe, and efficient manner. Nuclear production of hydrogen could enable a massive production of hydrogen at affordable prices while also reducing environmental pollution by cutting down on carbon dioxide emissions. Otherwise, both the need of using low-carbon energy sources and a significant advantage of SMRs as their adaptability to be coupled with other energy systems, like hydrogen production plants to generate a cogeneration plant. A Gas-Turbine High-Temperature Reactor (GT-HTR300) is an efficient reactor that can be used with the thermo-chemical Sulfur Iodine (SI) cycle to produce hydrogen []. To evaluate the economy of the nuclear hydrogen production system, the International Atomic Energy Agency (IAEA) has developed software tools such as HEEP (Hydrogen Economy Evaluation Program) [2, 3]. This paper uses HEEP to calculate the Levelized Unit Hydrogen Cost (LUHC) for a nuclear hydrogen production plant consisting of two modules of 300 MWth GT-HTR coupled with the SI process.

# Performance Analysis of SMR Plant with Steam Heating for Multi-purpose Applications


**Speaker: J.-s. Moon**

Primary Author: Jongseol Moon [1]

*[1] Central Research Institute, Korea Hydro and Nuclear Power*


**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 5: Non-Electric Applications for SMR (A.5)

**INDICO Abstract ID: 168**


**Abstract**

SMR plants can be downsized by configuring fewer equipment and systems compare to conventional nuclear power plants. In addition, SMR plants have versatile applications beyond electricity generation, including hydrogen production, heat supply, etc. In this study, a virtual SMR plant was selected and the plant heat balance was modeled using PEPSE software. Based on the established heat balance model, the plant performance, power output and efficiency, were assessed based on changes in design conditions. Furthermore, a high-temperature steam heating model using an electric heater was implemented for the multi-purpose utilization of SMR, and also the plant performances were evaluated concerning the desired target steam temperature and the amount of extracted steam. This study confirmed a significant decline in plant performance with an increase in partial load operation ratio, and the absence of final feedwater heater enhanced the power output of the plant, but it was accompanied by a decrease in efficiency due to the lack of a regeneration cycle. Analysis showed that heating the extracted main steam using an electric heater led to a decrease in plant power output as both the amount of the extraction steam and target heating temperature increased. However, when the target steam temperature matched the extraction steam temperature, the plant electrical output decreased proportionally with the steam extraction quantity, with minimal impact on efficiency. This was attributed to the minimal load requirement of the electric heater.

# Evaluating the Viability of Small Modular Reactors for Non-Electric Applications in Kuwait: A Preliminary Assessment


**Speaker: B. Almutairi**

Primary Author: Bader Almutairi [1]

Co-Author: Shaikha Al-sanad [1]

*[1] Kuwait Institute for Scientific Research*


**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 5: Non-Electric Applications for SMR (A.5)

**INDICO Abstract ID: 188**


**Abstract**

Small Modular Reactors (SMRs) stand at the forefront of nuclear technology innovation, presenting a potential solution to the increasing energy demand while achieving net zero emissions by 2050. The operational flexibility of SMRs is a key focus, providing power for processing heat for industrial applications, desalination, hydrogen production, and electricity generation. In the context of Kuwait, which presently lacks a nuclear power infrastructure, SMRs emerge as a potential solution for meeting the nation's specific energy requirements and sustainability ambitions, including achieving the goal of net zero emissions by 2050. Our analysis leverages the IAEA comprehensive database on SMRs to provide policymakers with the latest advancements in SMR technologies if Kuwait decides to pursue a nuclear power program. While acknowledging that a Reactor Technology Assessment (RTA) requires an extensive, multidisciplinary effort and continuous stakeholder engagement that can evolve over the course of developing a nuclear power program, a preliminary RTA was conducted. This assessment aimed to determine the most suitable SMR technologies for Kuwait, focusing on reactor types and operational temperatures for cogeneration applications that could contribute to decarbonizing the desalination and oil/gas sectors. Our findings indicate that Pressurized Water SMRs (PWSMRs) are especially well-matched for lower-temperature applications, making them an ideal option for Kuwait's desalination industry. PWSMRs can supply electricity for desalination plants employing reverse osmosis technology, in addition to serving thermal processes in multi-stage flash distillation (MSF) and multiple-effect distillation (MED) plants. Concurrently, SMRs designed as high-

temperature gas-cooled reactors are recognized for their potential to facilitate high-temperature industrial processes that can be utilized in the upstream and downstream oil sectors and for hydrogen production.

# Decarbonizing Refining Processes: SMR deployment paving the way to Synthetic Fuels

**Speaker: E. Lambridis [1]**

Primary Author: Fabio Nouchy [2]

*[1] TBC; [2] Tractebel*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 5: Non-Electric Applications for SMR (A.5)

**INDICO Abstract ID: 211**

**Abstract**

While petroleum-based products constitute a primary contributor to global carbon emissions, our current lifestyle will remain reliant on them for decades to come. ` However, there is an opportunity to mitigate their environmental impact by focusing on the decarbonization of the refining process. A more ambitious approach involves repurposing existing installations to facilitate the production of synthetic fuels and products with lower carbon footprints. The whole process can be planned in the framework of an SMR deployment strategy, with the goal of colocalizing these advanced technologies in proximity to refineries, capitalizing both on the benefits of high-temperature steam for diverse applications and on a reliable supply of electricity. The paper presents a case study focusing on a petrochemical plant, delineating the challenges and opportunities associated with transitioning away from fossil fuels. After a brief introduction on the challenge ahead, the study will describe key aspects such the intricacies of typical streams, products, and processes within refineries. Then it will address the considered scenarios for decarbonizing existing installations through SMR, and include a few hazard-related considerations. This exploration provides insights into the feasibility of transitioning towards sustainable alternatives in the petrochemical industry.

# NHR200-II Reactor: Characteristics, Development, and Applications in Non-Electric Energy Systems

**Speaker: W. Zhang**

Primary Authors: Wenwen Zhang [1]; Wentao Hao [1]; Weihua Li [1]; Xingtuan Yang [1]

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**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 5: Non-Electric Applications for SMR (A.5)

**INDICO Abstract ID: 219**

**Abstract**

As the latest small modular pressurized water reactor developed by the Institute of Nuclear and New Energy Technology (INET) of Tsinghua University, the NHR200-II maintains all the technical advantages of its predecessors (NHR5, NHR200-I), including integrated layout, full-power natural circulation, self-pressurization, intermediate loop isolation, and passive safety. The off-site emergency measures are technically unnecessary due to the elimination of large-scale radioactive release. Simplified auxiliary systems and component design requirements make NHR200-II operationally more straightforward, enhancing its economic viability. NHR200-II can meet various market demands, such as residential heating, industrial processing steam, cogeneration, seawater desalination, and centralized cooling. Currently, the industrial steam supply system is in the design phase, with the reactor having a power of 200MW and a primary circuit pressure of 8.0MPa, capable of providing superheated steam above 1.6MPa for industrial processes. With increasing demands for greenhouse gas emission reduction and air pollution control in China and globally, NHR200-II is poised for more emerging opportunities.

# Small Modular Reactors and cogeneration: impact of steam extraction on power conversion performance

**Speaker: G. Masotti**

Primary Authors: Guido Masotti [1]; Stefano Lorenzi [1]; Marco Ricotti [1]

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**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 5: Non-Electric Applications for SMR (A.5)

**INDICO Abstract ID: 277**

**Abstract**

The evolving energy landscape requires a shift in the operational paradigm of nuclear power plants, traditionally employed as electric power generators, to meet the increasing need for grid flexibility and leverage dispatchable and low-carbon thermal power to decarbonise hard-to-abate processes. These requirements can be met by extracting steam from the power conversion cycle to drive non-electric applications, such as high-temperature steam electrolysis for hydrogen production, which is the reference end-use considered in this study. In this work, the impact of different steam extraction and return points in terms of pressure, temperature, and mass flow rate on the performance of the balance of plant of a light-water cooled Small Modular Reactor (SMR) is investigated. The power conversion system of the SMR has been modelled and optimised, aiming to maximise cycle efficiency in response to different cogeneration requirements (up to 36 MWth), using the EBSILON Professional tool. The results show that the steam reinjection points downstream of the heat delivery to the end-user have the largest impact on the overall cycle performance. Such analysis offers a general overview of nuclear cogeneration opportunities, providing a quantitative evaluation of the impact of converting an SMR's balance of plant to drive non-electric applications.

# Strategic Implications of the 10MW Experimental Power Reactor (RDE) in Non-Electric Nuclear Power Generation Applications in Indonesia

**Speaker: G. R. Sunaryo**

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*[1] BRIN*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 5: Non-Electric Applications for SMR (A.5)

**INDICO Abstract ID: 282**

**Abstract**

Indonesia, with its nearly 270 million inhabitants and an annual growth rate of 1% to 1.5%, faces significant challenges in meeting its rising energy demands, particularly in densely populated areas like Java and major cities such as Jakarta, Surabaya, and Bandung. BAPPENAS outlined in the RPJMN that Indonesia aimed to have operational nuclear power plants by 2019. Consequently, BATAN has led the development of the 10MWt Experimental Power Reactor (RDE) since 2014. RDE, utilizing High Temperature Gas Cooled Reactor (HTGR) technology, differs from the HTR-10 (High Temperature Reactor 10MW) developed by Tsinghua University China. Designed as a Small Modular Reactor (SMR), RDE relies on local industries, particularly 7MW turbines, holding strategic implications for Indonesia's nuclear energy development. The planned construction of RDE in the Pusat Penelitian Ilmu Pengetahuan dan Teknologi (PUSPIPTEK) Serpong area promises local benefits, with surplus electricity earmarked for public lighting. However, political funding cessation has stalled progress, limiting activities to design. RDE design activities merge scientific research with innovative technology, enhancing capabilities and fostering international collaboration, notably with the IAEA and Tsinghua University. Sustainability is evident in the PeLUIts-150 project, while internal collaboration with PT PERTAMINA and Nusantara Power focuses on hydrogen production using steam and electricity. Aligned with Indonesia's commitment to achieving Net Zero Emission (NZE) by 2060, PeLUITs-40 emphasizes green energy and local industry development. Despite sharing core dimensions with RDE, PeLUITs-40 boasts a higher power output of 40 MWth, resulting in a coolant flow four times that of

RDE. These advancements signify Indonesia's progress toward sustainable energy solutions and technological innovation in the nuclear sector.

# XAMR® a new energy solution for decarbonization

**Speaker: D. Briggs**

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**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 5: Non-Electric Applications for SMR (A.5)

**INDICO Abstract ID: 287**

**Abstract**

NAAREA (Nuclear Abundant Affordable Resourceful Energy for All) is a French company developing a new energy solution : the XAMR® (eXtrasmall Advanced Modular Reactor), a mass-produced molten salt fast neutron microreactor. NAAREA's XAMR® will be capable of generating electricity and/or heat from long-lived spent fuel produced by current conventional reactors. This paper aims to present how NAAREA envisions various applications for the purpose of decarbonizing human activities through its 80 megawatts thermal/ 40 megawatts electric reactor. Among these, the innovation of advanced nuclear lies in its ability to attack off-grid markets, such as medium-temperature (100-400°C) and high-temperature (400-600°C) industrial processes, district heating, electro-fuel production or carbon capture technologies. Given its technological choices, NAAREA will contribute locally to the construction of hybrid energy systems capable of securing the energy supply in addition to the electricity grid. The combination of molten salt technology and the miniaturization of the solution paves the way for a true decentralization of energy supply. In particular, the use of process or waste heat is made possible by the proximity to the consumer site. Besides, MSR's high safety standards will not only help qualify XAMR for many industrial and urban markets, but also ensure its acceptance and support by society.

# Techno-Economic Analysis of SMR Cogeneration with Desalination: A Case Study in Türkiye

**Speaker: O. Y. Kutlu**

Primary Author: Osman Kutlu [1]

*[1] TENMAK*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 5: Non-Electric Applications for SMR (A.5)

**INDICO Abstract ID: 323**

**Abstract**

In the face of escalating global water scarcity, integrating Small Modular Reactors (SMRs) with desalination emerges as a promising solution. This study assesses the feasibility and economic viability of SMRs for cogeneration with desalination, focusing on Türkiye. SMRs, compact nuclear reactors, offer a unique opportunity to generate electricity and produce clean water through desalination. We evaluate SMR cogeneration systems in various coastal regions of Türkiye, considering different desalination technologies. Using the IAEA DEEP program version 5.1 and a computer simulation model, we assess the economic efficiency of the system's annual operation, incorporating revenue from electricity and water sales. We also consider seasonal and daily variations in electricity prices and seawater temperature for a comprehensive evaluation. We use the Mixed Integer Linear Programming (MILP) algorithm to identify the best siting location, configuration, and operational strategies for the SMR cogeneration-desalination system, aiming to maximize the net present value (NPV). This study's findings offer valuable insights into SMRs' potential to address energy and water challenges. It also provides essential guidance for policymakers, energy planners, and stakeholders navigating the complex intersection of energy and water resource management, which can help Türkiye progress towards energy security and water sustainability amid increasing climate change pressures

# FORCE: A modeling approach to increase the value proposition for SMRs in non-electric applications

**Speaker: A. S. Epiney**

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*[1] Idaho National Laboratory*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 5: Non-Electric Applications for SMR (A.5)

**INDICO Abstract ID: 330**

**Abstract**

Traditionally, nuclear power plants exist to make electricity, but they also must produce a lot of heat. Today, roughly 40% of all energy is wasted. More efficient energy use would be better for the environment and for the plant owner. The U.S. Department of Energy's Office of Nuclear Energy supports a national laboratory Integrated Energy System (IES) program. The program conducts research, development, and deployment activities to expand the role of advanced nuclear energy including SMRs beyond supporting the electricity grid. Expanded roles include supplying energy to various industrial and transportation applications. The IES program has developed the FORCE computational framework. FORCE is applied to conduct analysis of the technical and economic viability of a range of possible nuclear energy IES configurations and, at the end, to optimize those configurations within different markets. For example, energy arbitrage with thermal energy storage or hydrogen production and storage has been evaluated using FORCE. In addition, an evaluation of gas, diesel and jet fuels synthesis using nuclear power has been completed. The full paper will detail the capabilities of the FORCE tool suite and provide an overview of currently studied application cases.

# Dynamic modelling of a nuclear hybrid energy system with hydrogen production via high temperature steam electrolysis

**Speaker: G. Masotti**

Primary Authors: Guido Masotti [1]; Paolo Colbertaldo [1]; Marco Ficili [1]; Stefano Lorenzi [1]; Riccardo Mauri [1]; Marco Ricotti [1]

*[1] Politecnico di Milano*

**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 5: Non-Electric Applications for SMR (A.5)

**INDICO Abstract ID: 341**

**Abstract**

Integrating Small Modular Reactors (SMRs) into nuclear hybrid energy systems (NHES) represents a promising approach to improving energy utilisation efficiency while balancing the intermittency of variable renewable sources. In particular, by flexibly allocating the SMR's thermal power either for electricity generation or to drive industrial processes, these systems can contribute to the energy transition and benefit from revenue streams from multiple markets. However, the strong coupling among the various subsystems leads to complex challenges in designing and operating the NHES. In this context, it is of paramount importance to investigate the dynamics of the system and to develop effective control strategies to meet variable load and industrial user requirements while complying with the operational constraints of the system. In this paper, an illustrative NHES architecture integrating a light-water cooled SMR with a high-temperature steam electrolysis hydrogen production plant is studied. The object-oriented modelling language Modelica is used to analyse the response of the system for different demand variations. The results show the potential impacts of varying commodity demands on the SMR's balance of plant and on the nuclear island, indicating that the NHES can meet highly variable demands while maintaining the reactor's power at a stable level.

# Integrating Small Modular Reactors into Hybrid Energy Systems: the TANDEM Modelica library

**Speaker: G. Simonini**

Primary Authors: Nicolas Alpy [1]; Augustin Baudoux [2]; Viola Ferrara [3]; Youssef Hammadi [3]; David Haubensack [1]; Dorian Jouret [2]; Stefano Lorenzi [4]; Guido Masotti [4]; Sylvain Mathonnière [1]; Giorgio Simonini [3]; Raphaël Talpin [1]; Bernard Tourneur [2]

*[1] CEA; [2] Tractabel; [3] EDF; [4] Politecnico di Milano*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 5: Non-Electric Applications for SMR (A.5)

**INDICO Abstract ID: 360**

**Abstract**

The rapid evolution of Small Modular Reactor (SMR) technology has triggered renewed interest in exploring innovative applications within the framework of nuclear hybrid energy systems. SMR, given their greater flexibility in terms of siting and power rates, are one of the most suitable candidates to be integrated in energy systems aimed at providing multiple energetic assets. In this context, feasibility studies as well as techno-economics analysis should be supported by proper modelling tools able to facilitate the integration of SMRs with other energy system components, such as renewable plants, energy storage systems, hydrogen production, etc. This paper presents the TANDEM Modelica library developed within the TANDEM Project – a Horizon Europe project aimed at developing methodologies and tools to facilitate the safe and efficient integration of SMRs into smart low-carbon hybrid energy systems. The TANDEM library is based on several staple libraries (e.g., ThermoPower, ThermoSysPro, Modelica Standard Library) from which the main components of a hybrid energy system are derived, e.g., NSSS, BoP and power conversion systems, electrical and thermal energy storage, electrical grid, conventional power plants, hydrogen production with low and high temperature electrolyzers, district heating…. The library is meant to be a versatile platform, offering a unified framework for the dynamic simulation and analysis of complex interactions within nuclear hybrid energy systems. Key features of the library include modularity, extensibility, and compatibility with existing library and simulation tools, including safety codes. Possible applications enabled by the library include the analysis of different operational strategies and the optimization of the hybrid energy

system configuration and components’ design in terms of efficiency, reliability and/or $CO_2$ emissions.

# Mapping the hydrogen economy in Ghana: the strategic contribution of Small Modular Reactors

**Speaker: F. B. Quansah**

Primary Author: Festus Brew Quansah (ghana Atomic Energy Commission) [1]

*[1] Ghana Atomic Energy Commission (Nuclear Power Institute)*

**Presentation Type: Oral**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 5: Non-Electric Applications for SMR (A.5)

**INDICO Abstract ID: 375**

**Abstract**

The conversation about economic development in Ghana is co-evolving with sustainability, technological innovation, and energy security through Nuclear Power. To maximise Nuclear Power in Ghana, the economic opportunities that lie ahead require a new and deep strategic focus, especially with the emergence of new SMR technologies. Cogeneration allows SMR technology to be deployed to produce hydrogen, water, salt, and heating beyond electricity. In the short to medium term, electricity demand appears to be the key concern in Ghana as driven by population increase and economic growth scenarios. In the longer term, however, the spotlight could shift to the potential of hydrogen as an alternative source of energy. What are the prospects of nuclear hydrogen in Ghana? What factors may drive these scenarios? What could be the potential contribution to the Ghanaian economy? What recommendations can structure or formalise the future hydrogen economy in Ghana? This paper attempts an analysis of a hydrogen economy in Ghanaian context. It uses a systems approach to synthesise critical elements that require consideration as Ghana transitions into a hydrogen economy, especially with the emergence of SMRs. The analysis will present a 'phased framework' which could inform policy from several perspectives: technical, social, regulatory, and economic.

# The Relevance of Nuclear Energy for District Heating

**Speaker: C. Dulac**

Primary Authors: Jan Bartak [1]; Cesar Dulac

Co-Author: A Vallée [1]

*[1] Calogena*

**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 5: Non-Electric Applications for SMR (A.5)

**INDICO Abstract ID: 379**

**Abstract**

Modernisation and expansion of district heating and cooling infrastructure is one of the most efficient measures to reduce consumption of fossil fuels in Europe. Today, district heating (DH) systems use mostly fossil fuels, which account for 60% of total production. Other low-carbon options, such as biomass and geothermal energy, have limitations due to competing uses or local availability. As many fossil-fired district heating systems are reaching the end of their life, they need to be replaced. Moreover, the EU aims to increase the share of DH in total heat demand from 12% in 2023 to 30% in 2030 and 50% in 2050. Nuclear reactors can be used for DH. The Calogena company proposes a 30 MWt small modular reactor designed for DH applications. The Calogena® water-cooled reactor uses a very simple and intrinsically safe design inspired by pool-type research reactors. It operates at low pressure of ~5 bar and temperature around 100°C. Calogena® has a small footprint and adapts flexibly to heating networks of different sizes. The DH infrastructure is deployed in urban or peri-urban areas, managed by municipalities and local energy companies. Calogena is confident that the simplicity and high level of intrinsic safety of the reactor will facilitate public acceptance. Currently, biomass is the most common solution to decarbonize DH. Nuclear sources will also allow to reduce the consumption of biomass to eliminate air pollution in cities and reserve its use for other more noble applications.

# The nuclear power plant with high temperature gas cooled reactor and chemical process equipment as an option for solving the problem of large scale production of low carbon hydrogen

**Speaker: V. Pavlikhina**

Primary Author: V. Pavlikhina [1]

Co-Authors: T. Ishchenko [1]; N. Kodochigov [1]; A. Lazarev [1]; V. Petrunin [1]; I. Shmelev [1]

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**Presentation Type: Poster**

**Group:** Topical Group A: SMR Design, Technology and Fuel Cycle

**Track:** Track 5: Non-Electric Applications for SMR (A.5)

**INDICO Abstract ID: 428**

## Abstract

Nuclear power is a reliable and stable source of energy in context of global reduction of carbon dioxide emissions. Nuclear power may be used for desalination of sea water, production of low-carbon hydrogen, district heating and other industrial applications.
The development of nuclear hydrogen energy in Russia involves both large-scale production of hydrogen and related products using thermochemical processes (for example, steam reforming of methane) at specialized nuclear power plants with high-temperature gas-cooled reactors, as well as local production of hydrogen by water electrolysis at electrolysis facilities powered by electricity from nuclear power plants.
This paper will describe the progress in development of an innovative project of Rosatom State Corporation, i.e. a nuclear power plant with the gas (helium)-cooled high-temperature reactor (HTGR) (with thermal capacity of 200 MW) integrated with chemical process equipment for hydrogen production. The purpose of the HTGR is to generate high-temperature thermal power to be transferred to the chemical process equipment for large-scale, competitive hydrogen production. The use of the HTGR as a source of thermal power will provide for significant reduction of carbon dioxide emissions that are inevitably produced in hydrogen production processes that use methane not only as a

raw material for steam reforming of methane, but also as a fuel to provide heat necessary for process running.

## Topical Group B: Legislative and Regulatory Frameworks

**Participating Member States and International Organizations:**

Belgium, Brazil, Canada, Chile, Egypt, Finland, Indonesia, Kenya, Libya, Namibia, Pakistan, Philippines, Poland, Republic of Korea, Russian Federation, Slovakia, Sweden, Türkiye, Ukraine, United Kingdom, United States

**Key Words:** convention, liability, standard, installation, cnsc, project, accident, pakistan, legal, analysis,

## Track 6: International and National Legal Frameworks and SMRs (B.6)

# Evaluation of Radioactive Waste Streams and Management Options for Molten Salt Small Modular Reactor

**Speaker: B. B. Acar**

Primary Author: Banu Bulut Acar [1]

*[1] Hacettepe University*

**Presentation Type: Poster**

**Group:** Topical Group B: Legislative and Regulatory Frameworks

**Track:** Track 6: International and National Legal Frameworks and SMRs (B.6)

**INDICO Abstract ID: 80**

**Abstract**

Small modular reactors as a strong candidate for the future of nuclear energy seem to be the prospective contributors to the spent fuel inventory of the world. There are more than 80 small modular reactor concepts with various core designs and fuel cycle options including molten salt small modular reactors which will produce various amounts of spent fuel with different radiological and chemical properties during the operation. Therefore, the characteristics of spent fuel and radioactive waste generated from proposed small modular reactor designs should be evaluated and the implications on the back-end nuclear fuel cycle stages should be assessed. Since the molten salt reactor fuels are completely different in form and design from the conventional fuels used in the current reactor technologies, to develop the technologies needed for the back-end fuel cycle stages, the characterization of spent fuel and the waste streams from a molten salt small modular reactor is crucial for the deployment of small modular reactors based on this technology. This work focuses on the evaluation of spent fuel inventory and radioactive waste streams for a molten salt-type small modular reactor and the identification of steps/technologies to be applied for the safe management of characterised radioactive wastes.

# Challenges and constraints related to the final stage of the SMR fuel cycle in the light of plans to implement SMR technology in Poland.

**Speaker: A. Miśkiewicz**

Primary Author: Agnieszka Miśkiewicz

Co-Authors: Irena Herdzik-koniecko [1]; Katarzyna Kiegiel [1]; Grażyna Zakrzewska-koltuniewicz [1]

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**Presentation Type: Poster**

**Group:** Topical Group B: Legislative and Regulatory Frameworks

**Track:** Track 6: International and National Legal Frameworks and SMRs (B.6)

**INDICO Abstract ID: 178**

**Abstract**

The Polish power sector is based mainly on fossil fuel combustion, of which more than 70% represent hard and brown coals. Current climate policy foresees a significant decrease of CO2 emission to the environment implicating the need for urgent transformation of power industry into a low-carbon sector. The strategic document of the Energy Policy of Poland until 2040 (PEP2040), setting the framework for the energy transformation, states that the decarbonization of the energy sector will be possible thanks to the implementation of nuclear energy and offshore wind energy. Recently, there is great interest to use small modular reactors which implies the need to carry out a number of works aimed at checking the feasibility of implementing SMR technology in Polish conditions. Among others, there is a necessity to conduct in-depth analyses concerning the final stage of the fuel cycle. The paper presents a comprehensive analysis of the possibility of deployment of SMRs in Poland including an initial selection of SMR technologies most suitable for use in Polish condition as well as the fuel cycle options for selected technologies. Challenges and constraints related to the management of spent nuclear fuel and ways to counteract them are also taken into account. Additionally, possible ways of management of spent fuel from SMR taking into account the possibility of using innovative methods of reprocessing, including solvent extraction for the separation of actinides has been considered. Acknowledgements: This research was funded by the International Atomic Energy Agency for Coordinated

Research Project (T13021) entitled: “Analysis of Aspects Related to the Back-End of the SMR Fuel Cycle as a Step Towards the Implementation of SMR Technology in Poland.”

# Decommissioning By Design (DBD) Concept of Indonesia's PeLUIt 150 MW Small Modular Reactors (SMR) Model: Challenge and Opportunity to Ensure Safety and Sustainability

**Speaker: R. B. Saragih [1]**

Primary Author: Renaldy Bernardo Saragih [2]

*[1] TBC; [2] Politeknik Teknologi Nuklir Indonesia*

**Presentation Type: Poster**

**Group:** Topical Group B: Legislative and Regulatory Frameworks

**Track:** Track 6: International and National Legal Frameworks and SMRs (B.6)

**INDICO Abstract ID: 224**

**Abstract**

The construction of nuclear reactors in Indonesia is moving towards a new phase marked by the plan to build the first nuclear power plant (NPP) which is planned to start in the near future, among the many existing nuclear power plant technologies, small modular reactor (SMR) type NPP was chosen because it is considered to have a high level of effectiveness and operational safety, so the risk of accidents can be very small. The SMR currently projected in Indonesia is named PeLUIt and has been licensed by the IAEA, SMR PeLUIt technology is 150 MW nuclear power plant based on the High Temperature Gas-cooled Reactor (HTGR) technology, with the helium-coolant and output thermal power of 150 MW. Before the implementation of the current PeLUIt NPP Development, one of the tasks is to ensure that every nuclear power plant reactor technology that will be built does not burden future generations and maintain the safety of future generations, so it is necessary to design a scheme for the implementation of decommissioning to waste management since the PeLUIt reactor was designed (before Development), but the implementation of decommissioning by design (DBD) designed in Indonesia certainly faces challenges ranging from Determination of relevant schemes by considering future conditions, the dynamics of each process during nuclear reactor operations, the absence of specific regulations, to the design of financing schemes. All existing challenges become opportunities that Indonesia which is seriously working on nuclear power plants to find new approaches that previously did not exist, especially on

the SMR technology itself through the implementation of decommissioning and waste management since the reactor design was made.

# The Channeling of Liability and Small Modular Reactors: is it at all adequate?

**Speaker: P. Nowakowska**

Primary Author: Patrycja Nowakowska [1]

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**Presentation Type: Oral**

**Group:** Topical Group B: Legislative and Regulatory Frameworks

**Track:** Track 6: International and National Legal Frameworks and SMRs (B.6)

**INDICO Abstract ID: 58**

**Abstract**

**The principle of channelling liability serves as a cornerstone of the regime for nuclear damage liability.** Conventions offer limited exceptions for operators to escape liability. However, despite leveraging established technologies, SMRs present a unique scenario with first-of-a-kind commercial deployment. The question arises as to whether the aforementioned circumstances warrant an augmented scope of liability for the supplier. **Hypothetically assuming an affirmative response,** crucial questions arise regarding the implementation of such enhanced liability: Should the channelling principle be abandoned in favour of joint and several liability? Alternatively, could existing recourse mechanisms be expanded, allowing operators to seek compensation beyond contractual agreements, for instance, by proving supplier negligence as a causal factor in an accident? The current regulatory landscape in the scope of the right to recourse may create negotiation impasses, potentially favouring the supplier's position and hindering the development of SMRs and its role in decarbonization. The outcome may also differ: if the technology supplier is held liable even on a recourse basis. This could significantly increase investment costs and render SMRs an uncompetitive market solution. **The issue is inextricably linked to liability limits.** Current liability limits vary across conventions and national legislation. Additionally, conventions offer different possibilities for reducing liability limits based on installation characteristics. While SMRs can currently be classified as low-risk installations, it is essential to consider harmonising regulations across conventions to acknowledge this distinction and potentially adjust permissible liability limits in conjunction with compatible channelling solutions. **It is important to try to find an answer to this debate.** This requires not only legal but also economic analyses of the potential costs for stakeholders. Any

changes must be introduced with respect to the legitimate interest of potential victims. The impact on the process of technology development and clean energy transition must also be a determining factor.

# Small modular reactors to decarbonize the industry: the impact of nuclear liability

**Speaker: X. Vásquez-maignan**

Primary Author: Ximena Vásquez-maignan [1]

*[1] White & Case*

**Presentation Type: Oral**

**Group:** Topical Group B: Legislative and Regulatory Frameworks

**Track:** Track 6: International and National Legal Frameworks and SMRs (B.6)

**INDICO Abstract ID: 160**

**Abstract**

Nuclear liability is a special regime that was adopted to ensure an adequate compensation of potential victims having suffered nuclear damage caused by a nuclear incident. It should also be considered when developing an SMR project to decarbonize industrial activities, as it will have an impact on the financial scheme, risk allocation and structure of the project. Among the provisions of the nuclear liability conventions that would apply, the following are the most important ones: - the definition of "**nuclear installation**". An SMR will be qualified as such, whatever its size and capacity. Determining the site of the nuclear installation is also crucial as nuclear liability only compensates off-site damage. - the definition of "**operator**". The operator is not automatically the licensee, other entities may bear the nuclear liability based on a number of criteria. It is also important to note that SMR vendors will have different approaches, as some expect to own and operate the reactors, while others will sell them to third parties who will take over or outsource the operator's role. - the definition of "**nuclear incident**". If damage is caused jointly by an incident taking place at the nuclear installation and at the industrial site, the nuclear liability conventions will determine who will compensate the victims. The siting of the SMR will be important to avoid such situation and to comply with the safety requirement applicable to both the SMR and the industrial site. - the definition of "**nuclear damage**" determines the financial consequences of an incident or of preventive measures. Finally, SMRs could be considered as **low risk** based on the safety assessment and other criteria. If that were the case, the operator would benefit from a lower nuclear liability and insurance amount. It may also allow more alternatives to the nuclear insurance pools.

# Dealing with Ignorance: Resilience for Nuclear Safety-Security

**Speaker: J. Widyatmanto**

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**Presentation Type: Poster**

**Group:** Topical Group B: Legislative and Regulatory Frameworks

**Track:** Track 6: International and National Legal Frameworks and SMRs (B.6)

**INDICO Abstract ID: 180**

## Abstract

How should ignorance be addressed in conceptualising nuclear safety-security (NSS) such that policymakers are better prepared in building new commercial nuclear power plants (NPPs)? In building nuclear power plants (NPPs), reducing uncertainties plays an important role in maintaining nuclear safety-security (NSS). Nuclear safety aims at mitigating accidents, while nuclear security aims at preventing malicious acts from individuals to access the equipment, both lead to radioactive hazards[1]. Nuclear safety and security are approaches dealing with uncertainties about future hazards by factoring in possible risks. However, it is difficult for these approaches to take the unknown unknowns – also sometimes called ignorance about the future – into account[2]. As a contribution from nuclear energy ethics, this paper proposes how to take ignorance into account via resilience thinking. We do this by 1) showing how current NSS conceptualisation and assessments emphasise on quantifying uncertainties; 2) explaining the importance of realising that ignorance remains and needs to be addressed as such beyond researches on reducing it; 3) suggesting how ignorance consideration from resilience thinking can strengthen NSS' emphasis on uncertainties; 4) showing how the strengthened NSS conceptualisation benefit nuclear policymaking with the development and commercialisation of small modular reactors (SMRs) as the example. **Keywords**: nuclear safety-security (NSS), uncertainties, ignorance, resilience thinking, nuclear energy ethics **References** 1. IAEA Nuclear Safety and Security Glossary. INTERNATIONAL ATOMIC ENERGY AGENCY; 2022. https://www.iaea.org/publications/15236/iaea-nuclear-safety-and-security-glossary 2.

Riesch H. Levels of Uncertainty. In: Roeser S, Hillerbrand R, Sandin P, Peterson M, eds. Handbook of Risk Theory. Springer Netherlands; 2012:87-110. doi:10.1007/978-94-007-1433-5_4

# ADVANCING NUCLEAR DESIGN: OPTIMIZING BURNABLE POISON CONFIGURATIONS FOR EXTENDED CYCLE SMALL MODULAR REACTORS

**Speaker: A. Dandi**

Primary Author: Aiman Dandi [1]

*[1] Libyan Atomic Energy Establishment*

**Presentation Type: Poster**

**Group:** Topical Group B: Legislative and Regulatory Frameworks

**Track:** Track 6: International and National Legal Frameworks and SMRs (B.6)

**INDICO Abstract ID: 181**

### Abstract

The study introduces a novel application of a burnable poison (BP) known as Double Tube Burnable Poison (DTBP). Two design concepts of DTBP were tested in a small modular reactor (SMR) to extend the operating cycle while maintaining low soluble boron concentration. These concepts can be loaded in various locations in the fuel assembly, providing greater flexibility in nuclear design. The design's adaptability allows for an increased poison effect with the ability to control the depletion speed of its absorber materials. Combining DTBP pins with Erbia pins resulted in a flat k-infinite letdown curve and a substantial reduction in excess reactivity. DeCART2D and MASTER codes were used for assembly and core calculations. The results indicated that the DTBP and Erbia core combination achieved a cycle length exceeding 3.5 Effective Full Power Years. Furthermore, the Critical Boron Concentration was reduced to 309 ppm, staying within design limitations related to the moderator temperature coefficient and maximum pin power peaking. This option's performance surpassed that of other alternatives.

# APPLICABILITY OF KENYA'S LEGAL FRAMEWORK TO SUPPORT THE DEPLOYMENT OF SMALL MODULAR REACTOR

**Speaker: C. Owino**

Primary Authors: Joe Mwangi; Collins Owino

Co-Authors: Ruth Achieng; Joseph Nduma; Erick Ohaga; Queenter Osoro

**Presentation Type: Oral**

**Group:** Topical Group B: Legislative and Regulatory Frameworks

**Track:** Track 6: International and National Legal Frameworks and SMRs (B.6)

**INDICO Abstract ID: 209**

## Abstract

**ABSTRACT** The advancement of Small Modular Reactor (SMR) technologies has garnered increased interest from embarking countries considering introducing nuclear power in their energy mix. This is attributed to the unique characteristics associated with SMR technologies such as: fitness for smaller electricity grids; suitability for non-electric application; scalability; and site flexibility. Both the technology developers and the technology recipient countries are developing and enhancing the existing and new infrastructure to support the deployment of SMR technologies. Despite the efforts to accelerate the deployment of the SMR, technology recipient countries face numerous obstacles including legal and regulatory issues, standardizations and supply chain. Kenya, an embarking country, has adopted the IAEA Milestone Approach for the implementation of its nuclear power programme and it is currently in phase II. According to the national energy master, Kenya plans to introduce about 300 MWe, SMR, to its national grid by 2036 and two (2) additional similar sized units to be added in subsequent years. To achieve the set timelines, Kenya initiated the development of a new and enhancement of existing legal framework to support safe, secure and peaceful utilization of nuclear technology. This includes development of the nuclear regulatory act, drafting of the nuclear policy and ratification of the requisite treaties and conventions. This paper assesses the adequacy of the aforementioned framework, the Nuclear Regulatory Act, to determine its suitability to support the deployment of the SMR in Kenya. The assessment identified areas of compatibility and gaps taking into consideration the international standards and the novel aspects of SMRs. The findings

of this research shall form a basis for the development of a comprehensive legal and regulatory framework for the deployment of SMRs in Kenya. **KEY WORDS:** Small Modular Reactor, Legal framework, Technology Recipient Countries , Nuclear Policy, Milestone Approach.

# Readiness of International Legal Instruments to Regulate SMR’s.

**Speaker: H.n. Naimbale**

Primary Authors: Hilma Naimbale [1]; Joseph Eiman [2]

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**Presentation Type: Oral**

**Group:** Topical Group B: Legislative and Regulatory Frameworks

**Track:** Track 6: International and National Legal Frameworks and SMRs (B.6)

**INDICO Abstract ID: 213**

**Abstract**

**Problem** There is a new wave of interest for the generation of nuclear power using SMR’s. The effectiveness and appropriateness of current international legal binding instruments to regulate Small Modular Reactors (SMRs) needs to be assessed and validated. There seems to be a consensus on the fact that international legal binding instruments are not ready to regulate and control SMRs. It is, therefore, a challenge that needs to be investigated and this study aims to unpack that. **Purpose** The purpose is to find and analyze international legal binding instruments compatibility and effectiveness in order to control SMRs. The authors will systematically study the identified international legal binding instruments under the auspices of the IAEA in the areas of safety, security, safeguards and nuclear liability, and highlight areas of alliance of sustainability to control SMRs. All the findings will be listed, and all the gaps will be identified. **Method** The analysis of identified international binding instruments with the aims to identify shortfall and gaps to correct in order to effectively regulate and ensure safety and security during the operational life of a SMR. **Conclusion** This conclusion aims to show out all the gaps that the methodologies of analysis had identified and also to propose possible solutions and amendments in order to become effective and compatible with SMRs. The authors hope that funding will be covered by the IAEA in order to write the full investigation study and present a paper at the Conference.

# Legal and Regulatory Challenges in Introducing SMR Technologies in Slovakia

**Speaker: M. Turner**

Primary Author: Mikulas Turner [1]

*[1] Nuclear Regulatory Authority of the SR*

**Presentation Type: Oral**

**Group:** Topical Group B: Legislative and Regulatory Frameworks

**Track:** Track 6: International and National Legal Frameworks and SMRs (B.6)

**INDICO Abstract ID: 240**

**Abstract**

Updated Energy and Climate Plan The updated Integrated National Energy and Climate Plan (Plan) is a strategic document in the field of energy and the environment until 2030. Part of the Plan is the safe use of nuclear energy as a low-carbon source of electricity. In terms of energy supply security and diversification efforts, the Plan confirms the importance of new innovative technologies. With regard to innovative technologies like Small Modular Reactors (SMRs), the Plan sees potential in their ability to meet the need for flexible energy supply in the form of electricity, hydrogen and heat for heating and industrial purposes. It is envisaged that the updated Plan will be approved in 2024. A feasibility study is under preparation to introduce SMR in Slovakia. Legal and regulatory framework The legal framework for nuclear energy consists of several laws and regulations. These legal instruments are based on EU legal instruments, international treaties and agreements and on IAEA Safety Standards and WENRA Reference Levels. Since in Slovakia only pressurised water reactors are in operation or are planned (PWR), new SMR technologies with different designs and technologies represent a challenge for the future particularly considering the possible impact of new technologies on the existing legal framework. A new policy and strategy for the safe use of nuclear energy is under preparation which will be a vision on how to face future challenges and expectations. The paper will present the present situation and the possible ways forward in the legal and regulatory framework to be ready for SMRs and new technologies.

# Novel Organizational Models for Advanced Reactors' Operations: the Implementation of A/CPPNM Obligations in the Context of Multiple Jurisdictions


**Speaker: M. Man**

Primary Author: Madalina Man (pacific Northwest National Laboratory) [1]

*[1] Pacific Northwest National Laboratory (PNNL)*


**Presentation Type: Oral**

**Group:** Topical Group B: Legislative and Regulatory Frameworks

**Track:** Track 6: International and National Legal Frameworks and SMRs (B.6)

**INDICO Abstract ID: 262**


**Abstract**

International commerce in small modular reactors (SMR) supplied from a state to another state is poised to expand considerably in the near term. "While most advanced reactors will likely be sited in conventional terrestrial locations, marine-based water cooled SMRs have been designed for deployment either as a barge-mounted floating power unit or as an immersible underwater power unit. In addition, underground deployment of SMRs is under consideration. […] New organizational models have been recently developed in connection with advanced reactors. Under the build, own, and operate (BOO) model, the supplier remains the owner and operator for the life of the facility. Under the build, own, operate, and transfer (BOOT) model, the supplier is initially the owner and operator of the facility, but the contract includes arrangements for the transfer of ownership and operation to the host country at a specified point in the life of the facility." (See Morris, Man, Marek, 2022) An advanced reactor may be transported across multiple jurisdictions and operated using the BOO and BOOT models. Such scenarios may pose challenges in the application and operationalization of Article 5 of the Convention on Physical Protection of Nuclear Material as amended (A/CPPNM). This paper analyzes the legal implications of multiple jurisdictions in the application of A/CPPNM Article 5 in the context of an SMR built, owned and operated by State A on the territory of State B. (Released under PNNL-SA-195388)

# From unclear to nuclear – A more effective licensing process in Sweden

**Speaker: A. O. Mowitz**

Primary Authors: Aino Obenius Mowitz (inquiry On Licensing Of Nuclear Power In Sweden, Government Offices In Sweden) [1]; Pernilla Sandgren (inquiry On Licensing Of Nuclear Power In Sweden, Government Offices In Sweden) [1]

*[1] Inquiry on licensing of nuclear power in Sweden (KN2023:04), Government Offices in Sweden*

**Presentation Type: Oral**

**Group:** Topical Group B: Legislative and Regulatory Frameworks

**Track:** Track 6: International and National Legal Frameworks and SMRs (B.6)

**INDICO Abstract ID: 359**

**Abstract**

The last decades the policy and decisions affecting nuclear power in Sweden have shifted many times. Since the referendum in the 1980's, setting a definite end time to year 2010 which later was lifted, the possibilities and interest to invest in new nuclear power has been very low. After the election in 2022, as in many other countries, policy has made a U-turn and the Swedish Government has expressed short and long-term goals for expansion of the use of nuclear energy in Sweden. As a step in the Swedish process for legal changes, in November 2023 the Swedish Government decided to appoint a Committee of Inquiry to perform analysis and propose possible legal changes to clarify important pre-requisites and issues in the existing licensing process for nuclear power in Sweden. This paper gives an overview of the assignment and issues to be investigated by the committee, including an assessment of how the parallel and partly overlapping licensing processes according to the Environmental Code and the Act on Nuclear Activities can be made more effective and efficient, supporting international cooperation and with due account to nuclear safety, security and safeguards.

# Legal, institutional and policy instruments to facilitate deployment of nuclear power plants in Poland, including SMRs

**Speaker: K. Adamczyk**

Primary Author: Kamil Adamczyk [1]

*[1] Ministry of Climate and Environment*

**Presentation Type: Oral**

**Group:** Topical Group B: Legislative and Regulatory Frameworks

**Track:** Track 6: International and National Legal Frameworks and SMRs (B.6)

**INDICO Abstract ID: 378**

**Abstract**

Introducing nuclear power is among the top priorities of Poland's Energy Policy. The aim of the paper is to present legal, institutional and policy instruments adopted by the Polish Government and Parliament to facilitate deployment of nuclear power plants, with focus on those instruments that are particularly relevant to SMRs. The particular attention will be given to the special legislation adopted in 2023 aimed at reducing policy, licensing and investment risks related to construction of NPPs. The paper will present in particular the following regulations/instruments: (1) prelicensing instruments, (2) regulations on Decision-in-principle (State's approval of NPP investment project) (3) regulations to streamline licensing procedures related to environmental impact assessment, siting and construction of nuclear power plant (e.g. mechanisms of parallel administrative proceedings) (4) regulations to facilitate investment process (such as "fast-track" to construct accompanying infrastructure - energy lines, roads, railways etc; instruments to facilitate preconstruction activities etc.). Many of the above instruments reflect IAEA recommendations and special regulations that has streamlined various non-nuclear large-scale investments in Poland over recent years, in such areas as aviation (airports) or LNG industry. In addition the paper will give overview of the relevant institutional and policy instruments (closely linked to the legal framework) such as Committee for Nuclear Power acting within the framework of NEPIO. Conclusions presented in the paper may be useful for every country planning to develop legal framework for SMRs (as well as other types of nuclear power plants).

# Analysis of Neutronic Performance for SMART Reactor With Uranium Nitride and Thorium Fuel

**Speaker: M. I. Aziz**

Primary Author: Moustafa Ibrahim [1]

*[1] head of nucleae safety department*

**Presentation Type: Poster**

**Group:** Topical Group B: Legislative and Regulatory Frameworks

**Track:** Track 7: Regulatory Considerations for SMRs (B.7)

**INDICO Abstract ID: 78**

**Abstract**

SMART (System-integrated Modular Advanced ReacTor), which is conceptually developed by KAERI (Korea Atomic Energy Research Institute), is a small-sized advanced integral PWR that produces 330 MW of thermal energy under full power operating conditions. Maximizing the life cycle of fuel inside the reactor core has an important economic factor. In addition, it reduces the volume of spent fuel and spent fuel storage pools inside the reactor. In this paper, Uranium nitride and Thorium fuels in addition to traditional UO2 fuel were used to increase the fuel cycle time inside the SMART reactor. A model of the reactor core has been designed by using MCNPX Computer code package. The multiplication factor was calculated for the fuel time period. The results showed that uranium nitride of the same fuel enrichment gives a higher fuel cycle length than uranium oxide. The breeding ratio was compared between the different types of fuel that have been used. The isotopes produced as a result of burning and irradiating the fuel inside the reactor core are calculated. Safety parameters such as fuel and moderator temperature coefficient of reactivity were calculated for all fuel types. The Prompt neutrons lifetimes and the delayed neutrons fraction were also calculated and compared

# Regulatory Implications of Advanced Technologies for Advanced Reactors

**Speaker: R. Iyengar**

Primary Authors: Raj Iyengar (u.s. Nuclear Regulatory Commission) [1]; John Matrachisia (u.s. Nuclear Regulatory Commission) [1]; Thomas Scarbrough (u.s. Nuclear Regulatory Commission) [1]

*[1] U.S. Nuclear Regulatory Commission (United States)*

**Presentation Type: Oral**

**Group:** Topical Group B: Legislative and Regulatory Frameworks

**Track:** Track 7: Regulatory Considerations for SMRs (B.7)

**INDICO Abstract ID: 417**

**Abstract**

With the increased interest and activities in development of commercial advanced reactors and their fuels, the U.S. Nuclear Regulatory Commission (NRC) is assessing potential use of advanced technologies to minimize risk and uncertainties related to reactors operations and maintenance, within its flexible regulatory framework. To aid this assessment, the NRC staff is engaged in several research activities to expand their understanding of the key technical and regulatory considerations of use of advanced modeling and simulation and digital twins for condition monitoring of reactor structures and components. The outcome of these activities is intended to ensure staff readiness to review near-term licensing/certification actions, support pre-application engagements, and inform guidance development, as needed. The paper will highlight opportunities afforded by digital twins enabling technology, such as qualification requirements for mechanical systems and components, verification and validation and uncertainty quantification for advanced modeling and simulation, explainability and trustworthiness for artificial intelligence/machine learning (AI/ML). Further, the paper will underscore the use of advanced technologies to enable effective integration of safety, security, and safeguards (3S) to further inform NRC supporting activities to risk-inform and better equip the agency's readiness and posture to address applicants' and licensees' regulatory needs. This paper will also provide an overview of the various research activities and a summary of the recently completed reports.

# Preparation of Regulatory Framework for SMR Deployment in Ukraine

**Speaker: O. Dybach**

Primary Author: Oleksii Dybach (state Scientific And Technical Center For Nuclear And Radiation Safety) [1]

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**Presentation Type: Oral**

**Group:** Topical Group B: Legislative and Regulatory Frameworks

**Track:** Track 7: Regulatory Considerations for SMRs (B.7)

**INDICO Abstract ID: 144**

**Abstract**

Small modular reactors (SMRs) is widely considered as an essential part of an energy mix portfolio to reach the climate goals. In addition to their announced ability to generate clean, affordable and reliable power, Ukraine looks at SMRs also for decentralization the power system and to reduce its vulnerability to external impacts. International experience shows the benefits of early involvement of the regulatory body into the licensing process that could take different forms (design certification, generic design assessment, pre-licensing assessment, etc.) and the necessity for the regulator to advance prepare the framework for further regulating of new technologies. The Ukrainian national regulator SNRIU has been implementing a set of measures to prepare the national regulatory framework for SMR deployment. There are continued efforts on revising the national regulations moving from prescriptive to performance-based and technology neutral regulations. Furthermore, considering the current best international practice, the specific guidance “Provisions for Pre-Licensing Review of Nuclear Facility’s Design” (2023) was issued to outline a technical frame for pre-licensing review. The guidance was developed under cooperation between the US NRC and the SNRIU. SSTC NRS, as a SNRIU’s technical support organisation, is performing a basic study and pre-licensing review of a SMR design promising for further deployment in Ukraine. SSTC NRS

applies the national regulations as well as international standards and safety assessment methods for deriving principle judgments on the SMRs documentation. The review enables SSTC NRS experts to acquaint with a SMR design and to reveal the regulatory and technical challenges which could appear in the future licensing. The paper presents the overview of the guidance on pre-licensing review, experience in its application and respective lessons learned to be shared on the SMR Conference.

# Adaptiveness of the US NRC Regulatory Framework to Review Risk-Informed SMR Designs


**Speaker: G. Bowman [1]**

Primary Author: Sunil Weerakkody [2]

*[1] TBC; [2] US Nuclear Regulatory Commission*


**Presentation Type: Oral**

**Group:** Topical Group B: Legislative and Regulatory Frameworks

**Track:** Track 7: Regulatory Considerations for SMRs (B.7)

**INDICO Abstract ID: 208**


**Abstract**

The new generation of Small Modular Reactors (SMRs) have proposed safety strategies whose reliance on PSA (Probabilistic Safety Assessment), and consequently use of risk insights, have significantly varied. For instance, the Licensing Modernization Project (LMP) endorsed by the NRC using its Regulatory Guide 1.233, “Guidance for a Technology-Inclusive, Risk-Informed, and Performance-Based Methodology to Inform the Licensing Basis and Content of Applications for Licenses, Certifications, and Approvals for Non-Light-Water Reactors,” relies on PSA to classify systems, define the licensing basis events, and determine the adequacy of defense-in-depth of the design. Other approaches such as those proposed in ANSI/ANS-30.3-2022, “Light Water Reactor Risk-Informed, Performance-Based Design,” has a lower reliance on PSA, however, relies heavily on computed event frequencies to select key safety strategy attributes. Other proposed approaches use defense-in-depth as its foundation to ensure safety and use PSA to identify vulnerabilities and close any safety gaps. NRC has already reviewed some SMR designs and has begun reviewing several other SMR designs and/or the associated safety strategies. These SMR designers have developed innovative approaches to use risk-informed and performance-based methods in a variety of safety strategies. Applicants have attempted to develop these safety strategies to comport with the US NRC regulatory framework while at the same time meet with key components of other international frameworks such as the IAEA framework. US NRC has been adaptive to accommodate innovative approaches by leveraging risk insights. US NRC continues to optimize regulatory licensing and construction oversight pathways using lessons learned during its reviews. The proposed paper will summarize numerous

ways in which the U.S. NRC has used risk insights, where appropriate, to innovate and adapt its review approach.

# Adapting to Innovation: The Role of Regulatory Oversight in the Emerging Era of Small Modular Reactors

**Speaker: E. Mayaka**

Primary Author: Edward Mayaka [1]

*[1] Kenya Nuclear Regulatory Authority*

**Presentation Type: Oral**

**Group:** Topical Group B: Legislative and Regulatory Frameworks

**Track:** Track 7: Regulatory Considerations for SMRs (B.7)

**INDICO Abstract ID: 5**

**Abstract**

Recently, there has been a surge in interest in Small Modular Reactors (SMRs), especially in developing and newly industrializing countries. Recognized for their potential as a low-carbon, competitive option in future integrated energy systems. A critical aspect of SMR deployment is the development and implementation of a structured regulatory oversight program. This is essential not only for ensuring the safe and secure operation of SMRs but also for bolstering confidence in this emerging technology. Moreover, the introduction of SMRs presents unique challenges. These include their novelty and the significantly shorter construction time as compared to the longer periods required for traditional nuclear power plants. This paper delves into the strategic actions of the Kenya Nuclear Regulatory Authority (KNRA) in evaluating and improving their regulatory framework, with a focus on the safe and secure use of SMRs. As Kenya steps into the nuclear technology arena, it has initiated crucial steps such as developing a leadership model that embodies the principles and values of a national nuclear regulator, identifying and defining key processes crucial for the regulatory body's efficient functioning. The paper also highlights the development of a tailored organizational structure aligned with the current strategic plan and emphasizes the importance of identifying and prioritizing essential competencies vital for effective regulation and management of nuclear technology.

# Regulatory considerations for SMR application: The case of South Korea

**Speaker: Y. Suh**

Primary Author: Young-a Suh [1]

Co-Authors: Youn Young Jang [1]; Kyuntae Kim [1]

*[1] Korea Institute of Nuclear Safety*

**Presentation Type: Oral**

**Group:** Topical Group B: Legislative and Regulatory Frameworks

**Track:** Track 7: Regulatory Considerations for SMRs (B.7)

**INDICO Abstract ID: 50**

**Abstract**

Small module reactors (SMRs) are in the spotlight worldwide as a means of carbon neutrality primarily because of their safety and economic feasibility. South Korea is in the process of developing an innovative SMR(iSMR), with a licensing goal of 2028. It is necessary to reorganize regulatory requirements and improve the framework as the development of domestic SMRs, including iSMR, increases rapidly. For the above reasons, the KINS has promoted regulatory improvement R&D (2022-2028) aimed at developing a safety regulatory framework specialized for SMRs and a pre-licensing safety review (PLR) program. In addition, the Korean regulatory bodies (KINS and NSSC) have prepared PLR procedures and policy statements for SMR regulation to improve SMR licensing efficiency. Thus, this paper suggests the consideration of regulators reflecting changes in the regulatory environment to SMR through the current status and readiness of regulatory activities for SMR.

# APPROACHES TO IMPROVING SAFETY REQUIREMENTS IN CONNECTION WITH THE DEVELOPMENT AND IMPLEMENTATION OF SMALL MODULAR REACTORS TECHNOLOGIES

**Speaker: V. Khlobystov**

Primary Authors: Andrey Kirkin [1]; Valerii Khlobystov [2]; Anton Kuryndin [2]; Sergey Sinegribov (scientific And Engineering Centre For Nuclear And Radiation Safety) [3]

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**Presentation Type: Oral**

**Group:** Topical Group B: Legislative and Regulatory Frameworks

**Track:** Track 7: Regulatory Considerations for SMRs (B.7)

**INDICO Abstract ID: 61**

**Abstract**

Innovative technologies development in the field of atomic energy use, including small modular reactors, is accompanied by development and implementation of new design decisions as well as technical and organizational measures to ensure safety. This, in turn, leads to the necessity to develop new safety requirements for small modular reactors to ensure successful and safe functioning of the nuclear power industrial complex. The above-mentioned activities should be preceded by the comprehensive work, including assessment of the completeness and sufficiency of the national legal and regulatory framework; analysis of the international experience; analysis and evaluation of proposed innovative solutions; development of approaches to account the specifics of small modular reactors when regulating safety. Over the past few years in the Russian Federation, as part of the development of nuclear energy technologies, a significant amount of work has been carried out on the creation of small modular reactors, including the water-cooled reactors (RITM-200 and SHELF-M) and high temperature gas-cooled reactors (VTGR). The report demonstrates the impact of the development of small modular reactor technologies on the processes of improving the legal and regulatory framework in order to establish additional specialized rules and regulations that take into account the specifics of the most promising small modular

reactors. Among other things, the report includes information on approaches to conducting pre-licensing analysis and evaluation of safety justifications for small modular reactor projects close to implementation, as well as approaches to organizing interaction between the regulatory body (Rostechnadzor) and the authorized body for control of the atomic energy use, operating organizations, designers and other organizations involved in the deployment of small modular reactors.

# A new approach to regulation

**Speaker: S. Stuttaford**

Primary Author: Simon Stuttaford

**Presentation Type: Oral**

**Group:** Topical Group B: Legislative and Regulatory Frameworks

**Track:** Track 7: Regulatory Considerations for SMRs (B.7)

**INDICO Abstract ID: 63**

**Abstract**

Advanced nuclear technologies have a significant role in addressing the global climate change challenge and decarbonisation efforts. But there is a pressing requirement for a change in the regulatory approach. Licensing is a key topic that would benefit from a more targeted approach. Licensing regimes are based on conventional large reactors and this means that the innovative attributes of the wide range of SMR designs are most likely to challenge the existing framework. The existing traditional nuclear licensing processes are lengthy in duration, high in cost and adopt conservative and stringent regulatory requirements. In addition, specific ownership/Licensee models may look different for SMRs, presenting a challenge for Regulators. Harmonization or Standardization may well be the ultimate goal, but until we get there we need to consider a new approach. Our proposal is that under the supervision of the IAEA (or perhaps a designated expert-led body of the IAEA), a design approval in one jurisdiction should be capable of transfer to another jurisdiction, subject to any specific points that the “adopting” Regulator wishes to examine. In practice, we are seeing a move in this direction, evidenced by an increasing number of multilateral/bilateral initiatives and numerous examples of cooperation between Regulators.

# Safety Analysis of Small Modular Reactors in the context of the Polish regulatory framework

**Speaker: P. Darnowski**

Primary Authors: Piotr Darnowski [1]; Dominik Rauchut [1]; Klaudia Reinert [1]

*[1] National Atomic Energy Agency*

**Presentation Type: Poster**

**Group:** Topical Group B: Legislative and Regulatory Frameworks

**Track:** Track 7: Regulatory Considerations for SMRs (B.7)

**INDICO Abstract ID: 77**

**Abstract**

Small Modular Reactors (SMR) gained a lot of interest in the Polish industry with their potential to provide a baseload carbon-free source of electricity and other commodities like process heat. Poland has a few nuclear facilities, including a research reactor (MARIA) and a licensing framework with the regulatory body, the National Atomic Energy Agency (Państwowa Agencja Atomistyki - PAA). Nevertheless, there are no commercial nuclear power plants, and this creates specific challenges for both the regulatory body and the nuclear industry. One of the challenges is applying the current licensing framework for advanced reactor technologies, including SMRs. Another is to improve the current framework or build a new framework that will be suitable for new technologies. Safety analysis of innovative reactors (e.g., SMRs) is one of several critical topics within regulatory process. This work focuses on the current Polish regulations related to safety analysis in the context of advanced reactors and especially SMRs. In the paper, selected topics related to safety analysis are discussed, potential obstacles are identified, and conclusions that can be useful for PAA or other involved organizations are drawn.

# Licensing Challenges for Risk-Informed Small Modular Reactor Designs in European Deterministic Regulatory Frameworks

**Speaker: J. Rega**

Primary Author: Jo Rega [1]

Co-Author: Philippe Dejardin [1]

*[1] Tractebel*

**Presentation Type: Oral**

**Group:** Topical Group B: Legislative and Regulatory Frameworks

**Track:** Track 7: Regulatory Considerations for SMRs (B.7)

**INDICO Abstract ID: 101**

**Abstract**

Small Modular Reactors (SMRs) represent a promising advancement in nuclear technology, offering enhanced safety features, scalability, and flexibility compared to traditional large-scale reactors. The use of passive safety features combined with the lower source term make an SMR inherently safer than a large Nuclear Power Plant (NPP) and opens the possibility for optimization of the design through a graded approach. Explicit guidance for the grading down of SMR related requirements and recommendations is lacking. Certain SMR-designs have used a risk-informed approach to achieve an overall optimization of safety measures, supporting the effective and balanced implementation of the defence in depth concept. However, their deployment faces significant licensing challenges in countries with deterministic regulatory frameworks, which prioritize prescriptive safety standards over risk-informed approaches. This paper explores the complex interplay between risk-informed design methodologies and deterministic regulatory requirements in the licensing process for SMRs. It examines the tension between the desire for innovation and the regulatory imperative for rigorous safety assurance, highlighting a balanced approach that integrates risk assessment principles into existing regulatory frameworks. Through a comparative analysis, this paper identifies key barriers and licensing challenges associated with risk-informed SMR designs within deterministic regulatory environments. Additionally, it underscores the importance of stakeholder engagement, regulatory harmonization, and knowledge sharing to foster a conducive regulatory

environment that promotes the safe and efficient deployment of SMRs while ensuring regulatory compliance.

# Issues and Challenges of Regulatory Framework for Deployment of SMRs — Pakistan Perspective

**Speaker: M. Asghar**

Primary Author: Muhammad Asghar [1]

*[1] PAEC*

**Presentation Type: Oral**

**Group:** Topical Group B: Legislative and Regulatory Frameworks

**Track:** Track 7: Regulatory Considerations for SMRs (B.7)

**INDICO Abstract ID: 135**

**Abstract**

ABSTRACT The increasing interest in Small Modular Nuclear Reactors (SMRs) is primarily governed by the climate change. SMRs are unique in design in contrast to existing fleet of nuclear power plants thus regulatory framework should be tailored in areas of licensing, design, siting, manufacturing including emergency preparedness and response. Nuclear regulatory agencies around the world including Pakistan Nuclear Regulatory Authority (PNRA) is facing new challenges e.g. licensing of smaller-scale reactor, different FOAK designs, factory production of units, innovative safety measures, multiple-modules with one control center, deployment near populous areas with application of co-generation (e.g. hydrogen production, district heating, desalination) smaller site footprint etc. SMR designs concepts may challenge our existing national laws and regulations and may need to be tailored to support graded approach to facilitate the licensing process e.g. unique design, multi-modules, national/international design certification, third party nuclear civil liability etc. There might be many legal issues that need to be resolved among different countries such as Intellectual Property Rights (IPRs), safeguard issues. The harmonization and standardization at global scale is another challenge. The smooth licensing process for SMRs is the key to their successful deployment. The safety requirements for design also facing new challenges such as devising a mechanism for application of defense-in-depth (DiD) in parallel with innovation, integration and modularity. Also, application of design extension conditions and practical elimination of high consequences and low probability event with high confidence level will be a principal challenge. Site specific conditions also pose challenges in the deployment of SMRs. It includes, but not limited to, proximity of SMRs to hazardous facility such as hydrogen, chemical industries, refineries etc., fulfillment of

exclusion area boundary and low population zone requirements near population centers, feasibility of emergency planning zones and protective actions in close proximity of cities etc.

# Features and Principles of Regulatory Regulation for the Project of Land-Based SNPP with RITM200N Reactor Plant

**Speakers: I. Bykh; D. Shchekin;  [1]; I. Yurina**

Primary Authors: Iaroslav Bykh; Dmitriy Shchekin [2]; Inna Yurina [2]

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**Presentation Type: Oral**

**Group:** Topical Group B: Legislative and Regulatory Frameworks

**Track:** Track 7: Regulatory Considerations for SMRs (B.7)

**INDICO Abstract ID: 137**

**Abstract**

Currently, State Corporation Rosatom is developing a wide range of SNPP based on RITM-200-type reactor plants. The flagship project in the segment of land-based SNPP is a nuclear power plant with 55 MW (el) RITM-200N reactor plant designed on the basis of RITM-200 RP. Afrikantov OKBM JSC - an enterprise of nuclear engineering with many years of experience in the development and operation of marine reactors. In order to bring the technical solutions of the land-based SNPP into compliance with the RITM-200N RP and the regulatory legal acts in force in the Russian Federation, as well as taking into account the requirements and recommendations of international regulatory documents, it was decided to create an intersectoral working group on regulatory documentation used in the project of the land-based SNPP with the RITM200N RP. One of the key areas of work is the alignment of the accepted design solutions of the RITM-200N RP with the current legislation, the development of compensating measures for identified deviations from regulatory documents, the adjustment of federal standards and rules, development of standardization documents. Within the framework of these activities, the developers of the project of land-based SNPP with the RITM-200N RP are interacting with the Federal Service for Environmental, Technological and Nuclear Supervision (Rostechnadzor) regarding the application of the requirements of the current legislation of the Russian Federation in the field of atomic energy use for nuclear power plants to the RITM-200 project for SNPP. In the world community and international organizations, such as IAEA, WENRA, EUR, there are also active discussions on the possibility and features of applying existing regulatory requirements to the regulation and safety of small modular reactors. The project of land-based SNPP with

RITM-200N RP is developed taking into account the requirements of international rules and regulations.

# Developing regulatory framework for SMRs

**Speaker: E. Ahonen [1]**

Primary Author: Minna Tuomainen

*[1] TBC*

**Presentation Type: Oral**

**Group:** Topical Group B: Legislative and Regulatory Frameworks

**Track:** Track 7: Regulatory Considerations for SMRs (B.7)

**INDICO Abstract ID: 139**

**Abstract**

The current regulatory framework for power reactors in Finland is designed to regulate large light water reactors intended for electricity production, located in relatively remote areas and constructed and operated by well-established nuclear power companies with extensive in-house competence. However, the growing interest in Small Modular Reactors (SMRs), particularly for district heating purposes, challenges the validity of these assumptions. The regulatory framework is being developed to serve varying approaches to deploying nuclear energy and to enable emerging technologies, when demonstrated to be safe. A comprehensive reform of related legislation is currently in progress. Both the licensing process and safety requirements are being thoroughly reviewed and adjusted as needed. Concurrently, STUK is adapting its oversight practices accordingly. This paper outlines how SMRs are being considered in the reform. It includes practical examples to illustrate the work. The first example involves revising regulations to permit a case-by-case definition of emergency planning zones. The second example addresses the establishment of a pre-licensing step for evaluating designs before entering construction license phase. The third case discusses the utilization of design evaluations, such as the joint early review of Nuward, to support the development of the regulatory framework.

# Regulatory Gap Analysis for i-SMR

**Speaker: S. J. Yoon**

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**Presentation Type: Oral**

**Group:** Topical Group B: Legislative and Regulatory Frameworks

**Track:** Track 7: Regulatory Considerations for SMRs (B.7)

**INDICO Abstract ID: 177**

**Abstract**

Korea government and nuclear industry now have been developing the new SMR called innovative SMR(i-SMR) by leading from the Korea government and KHNP(Korea Hydro and Nuclear Power company). KHNP sets the top tier requirements to secure the high level of safety, economic efficiency and flexibility. The i-SMR adopts the new plant design including integrated modular reactor, fully passive engineered safety features, and boron-free system. Due to the characteristics of i-SMR design, it will be anticipated that there are difficulties to apply the existing light water reactor regulatory requirements and guidance to achieve standard design approval by Korea nuclear regulatory body. In this paper, the results of the KHNP gap analysis assessment are summarized. First, the analysis involved a detail review of nuclear safety laws(including technical standards) of the Korea regulatory body are performed. Afterward, the KHNP derives the "16 gaps" inappropriate with the existing LWR-based regulations and technical guidelines. These gaps are including system improvement and safety standards(aspect of safety analysis, non-safety class electrical system, passive safety system etc.). The KHNP had published the gap analysis report to prepare for pre-design review for standard design approval. The KHNP will continuosly try to establish new regulatory standards and guidelines suitable for i-SMR.

# Small Modular Reactors - A Regulatory Perspectivein Pakistan

**Speaker: K.u. Rahman**

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**Presentation Type: Oral**

**Group:** Topical Group B: Legislative and Regulatory Frameworks

**Track:** Track 7: Regulatory Considerations for SMRs (B.7)

**INDICO Abstract ID: 183**

**Abstract**

In recent years, small modular reactors (SMRs) based novel technologies had emerged and become a center of attention in terms of a cost effective and flexible energy solution, owing to their enhanced passive safety features, modularity in design, factory fabrication and modern reactor concepts etc. Currently, traditional PWR based nuclear power plants (NPPs) are being operated and regulated in Pakistan through a robust nuclear regulatory framework that covers all stages throughout a life cycle of NPP (i.e. siting, design evaluation, construction commissioning, operation and decommissioning). With the advent of Small Modular Reactors (SMRs) technologies in recent years, it is realized that there is a need to verify the appropriateness of existing framework for licensing of these technologies capable to supply power to smaller electrical grids or to remote, off-grid areas. These SMRs are typically smaller than traditional nuclear power plants and can also be located on sites that differ from those of traditional nuclear power plants and have ability to generate flexible power as per electricity demand and may be deployed on small grids or at off-grid locations. Deployment of SMR can also be a future option considering energy mix of Pakistan. The novel approaches in the design and deployment of SMRs can pose challenges to the existing regulatory framework. Considering these novel design features with respect to conventional NPPs, there is need to identify gaps in current regulatory framework / licensing approaches. This paper will identify and discuss the areas that need to be considered for making necessary changes in current regulatory framework of Pakistan.

# Regulatory Readiness and Challenges for Small Modular Reactors Deployment: The Philippine Perspective

**Speaker: J.l. Sablay**

Primary Author: Jeana Lee Sablay [1]

Co-Authors: Mary Gold Bulos [1]; Alfonso Singayan [1]

*[1] Philippine Nuclear Research Institute*

**Presentation Type: Oral**

**Group:** Topical Group B: Legislative and Regulatory Frameworks

**Track:** Track 7: Regulatory Considerations for SMRs (B.7)

**INDICO Abstract ID: 298**

**Abstract**

The Philippines faces a significant challenge in its efforts to incorporate nuclear energy into its energy portfolio by 2032. In such a short time frame, the country looks at Small Modular Reactors (SMRs) as a viable source of reliable baseload energy which can be deployed to major islands not connected to the main grid or to regions utilizing renewable energy sources. However, complex legislative and regulatory frameworks need to be updated to accommodate new developments in this field, posing a substantial hurdle to their implementation. With limited international experience in licensing SMRs, the question of whether the Philippines, a newcomer country, is prepared to implement this novel reactor technology arises. This paper explores the regulatory readiness and challenges associated with introducing SMRs in the Philippines. It examines the existing regulatory framework and its adaptability to SMRs, as well as the unique challenges, including public perception and stakeholder concerns around new nuclear technology. An in-depth analysis of international case studies offers valuable insights that help in formulating strategies for regulatory body readiness. This study also presents the importance of taking proactive measures, including training, international collaboration, and legal and regulatory amendments, to ensure smooth integration of SMRs in the Philippines.

# Regulatory considerations for the transportable eVinci microreactor


**Speaker: A. Spalding**

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**Presentation Type: Oral**

**Group:** Topical Group B: Legislative and Regulatory Frameworks

**Track:** Track 7: Regulatory Considerations for SMRs (B.7)

**INDICO Abstract ID: 331**


## Abstract

The proposed licensing path and deployment model for the eVinci microreactor utilizes various regulations and licenses. A deployment model will be presented which depicts the Westinghouse plan to successfully and safely deploy multiple eVinci microreactors in the future. The deployment model includes a nuclear test reactor to collect data and support the safety case, including code verification and validation (V&V). Westinghouse intends to pursue a Standard Design Certification (DC) with US NRC for the eVinci microreactor. Several steps of the deployment model may require additional licenses and are described below. An overview of the regulatory body lessons learned from assessing eVinci microreactor deployment, regulatory challenges, and anticipated regulatory framework innovations needed to support the unique deployment model will be detailed in this submission. There are several paths available to acquire the requisite regulatory approvals to enact the deployment model. Westinghouse plans to use Title 10 of the Code of Federal Regulations (CFR) Part 52 for the licensing of the eVinci microreactor standard design. A DC under 10 CFR Part 52 Subpart B will support deployment and future license applications of standard eVinci microreactors within the United States. In addition to a DC, Westinghouse intends to explore the various licenses that could be used to support eVinci microreactor deployment including a special nuclear material (SNM) license under 10 CFR Part 70, certificate of compliance (CoC) for a transportation package under 10 CFR Part 71, as well as other potential licenses for each stage of the eVinci microreactor deployment model.

# Regulatory requirements for managing supply chain for Small Modular Reactors in Canada

**Speaker: D. Papaz**

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**Presentation Type: Oral**

**Group:** Topical Group B: Legislative and Regulatory Frameworks

**Track:** Track 7: Regulatory Considerations for SMRs (B.7)

**INDICO Abstract ID: 345**

**Abstract**

The primary role of the Canadian Nuclear Safety Commission (CNSC) is to regulate the use of nuclear energy and materials to protect health, safety, security and the environment, including setting regulatory requirements for managing supply chain activities. The CNSC ensures that licensees effectively control the work of suppliers through oversight and inspection activities. CSA Group standard N286-12, Management system requirements for nuclear facilities provides requirements for the procurement of services and items for nuclear facilities. CNSC activities related to supply management include conducting technical reviews of the licensees' and supplier's documentation, inspection of oversight activities, and, indirectly, inspection of suppliers' processes. CNSC staff stay current with challenges and opportunities in the nuclear supply chain, offering guidance for regulatory improvement and staff skill development. For regulatory work related to the deployment of Small Modular Reactors (SMRs) in Canada, the CNSC has launched several supply chain initiatives, including: • Conducting international benchmarking to define best practices in regulatory supply chain oversight, • Creating a work instruction for Long Lead Items, • Issuing SMR supply chain inspection guides, and • Assessing manufacturing operating experience. These initiatives are discussed with industry. CNSC staff continue work to improve regulatory oversight of the entire supply chain.

# The role of regulation as an obstacle or an enabler of the SMR promise? Diverging industry and regulator views


**Speaker: M. Lehtonen**

Primary Authors: Matti Kojo [1]; Markku Lehtonen; Tapio Litmanen; Mika Kari

*[1] LUT University*


**Presentation Type: Oral**

**Group:** Topical Group B: Legislative and Regulatory Frameworks

**Track:** Track 7: Regulatory Considerations for SMRs (B.7)

**INDICO Abstract ID: 363**


**Abstract**

Regulatory reforms are underway, nationally and internationally, to streamline and harmonise nuclear safety regulation, to facilitate the deployment of SMRs. While some – both within and outside of the nuclear community – consider excessive and “fear-driven” safety regulation as the main obstacle to the commercialisation of SMRs, others in turn regard regulatory reform as secondary, blaming the nuclear industry for its inability to harmonize industry standards as the main bottleneck. This paper analyses the distinct views of industry, regulators, and politicians on the rationale and the role of the regulatory reforms in facilitating SMR development and deployment. It does so by examining the SMR reforms in Canada and Finland, two countries actively preparing for the deployment of SMRs, and representing the somewhat distinct European and North American regulatory regimes. The Canadian nuclear safety Commission (CNSC) continues to collaborate with the US NRC to streamline its safety regulation in preparation of the deployment of SMRs, whereas in Finland, a comprehensive reform of the Nuclear Energy Act is underway, partly to prepare for the possible introduction of SMRs. The paper first outlines the key elements of the regulatory reforms and regulatory contexts in the two countries. It then analyses stakeholder views via qualitative text analysis methods to publicly available government and industry documentation.

# Regulatory agility through use of performance-based regulations.

**Speaker: S. Belyea**

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*[1] Canadian Nuclear Safety Commission*

**Presentation Type: Oral**

**Group:** Topical Group B: Legislative and Regulatory Frameworks

**Track:** Track 7: Regulatory Considerations for SMRs (B.7)

**INDICO Abstract ID: 377**

**Abstract**

Performance-based regulation offers flexibility for modern and innovative technologies across many sectors, including nuclear. In Canada, like many other nations, nuclear regulatory frameworks evolved during the design and rollout of its first commercial reactors in the 1960’s to 1980’s. Canadian regulation at this time was heavily performance based, coupled with reliance on scientific judgement to make decisions for safety. In the decades that followed, regulations and standards evolved to include more prescriptive-based elements. Informed by operating experience, industry teamed with regulators to codify best practices on how to achieve safety. This approach, when coupled with a common national nuclear technology (CANDU) led to excellent safety standards that were prescriptive in nature. In recent years, the CNSC has focussed on the development of performance-based approaches in its Regulatory Framework to be in a better position to regulate new nuclear technologies that differ from its current CANDU fleet. The CNSC is also fortunate in that it embraces the use of a graded approach for regulation and allows the use of alternatives to meet regulatory requirements. This paper examines the advantages of employing performance-based regulation using a graded approach for advanced reactor designs. It also explores how prescriptive regulations and standards developed for traditional nuclear technologies can be effectively integrated into the regulatory framework for novel technology and newer advanced designs.

# New Nuclear Construction Compliance Oversight

**Speaker: A. Mathai**

Primary Author: Andrew Mathai [1]

*[1] Canadian Nuclear Safety Commission*

**Presentation Type: Poster**

**Group:** Topical Group B: Legislative and Regulatory Frameworks

**Track:** Track 7: Regulatory Considerations for SMRs (B.7)

**INDICO Abstract ID: 418**

**Abstract**

The Canadian Nuclear Safety Commission (CNSC) plays a crucial role in safeguarding public health, safety, security, and the environment by regulating nuclear energy and materials. As the landscape of nuclear technology evolves, particularly with the emergence of Small Modular Reactors (SMRs), the CNSC is proactively preparing to regulate these novel reactor technologies effectively. In anticipation of potential licensing and oversight responsibilities for Small Modular Reactors (SMRs), the CNSC aims to establish a robust compliance verification plan. Specifically, should the Commission grant a construction license for the Darlington New Nuclear Project in Canada, the CNSC will need to implement a compliance verification plan to ensure that licensees meet their obligations during the construction phase. This compliance plan must be adaptable and responsive, drawing upon existing CNSC oversight mechanisms such as the Risk Informed Decision Making (RIDM) process and incorporating both national and international Operating Experience (OPEX). The development of this plan involved a comprehensive assessment of various factors and a systematic approach to ensure its effectiveness. Furthermore, the CNSC is committed to staying abreast of advancements and challenges in advanced reactor technologies, integrating this knowledge into its compliance oversight efforts. Looking ahead, the CNSC aims to automate aspects of the compliance verification plan, facilitating its application to future construction projects regardless of technology or type. This strategic approach and ongoing efforts to enhance regulatory oversight will be shared with industry stakeholders.

# The Brazilian Nuclear licensing process for disruptive and innovative technologies

**Speaker: A. L. Barbosa Sousa**

Primary Authors: Anna Letícia Barbosa Sousa (national Nuclear Energy Commission) [1]; Nelbia Da Silva Lapa (national Nuclear Energy Commission) [1]

*[1] National Nuclear Energy Commission (CNEN)*

**Presentation Type: Oral**

**Group:** Topical Group B: Legislative and Regulatory Frameworks

**Track:** Track 7: Regulatory Considerations for SMRs (B.7)

**INDICO Abstract ID: 419**

**Abstract**

One of the biggest challenges of this century will be to adapt the energy production to the country's needs. This production must harmonize low cost, reduced environmental footprint and low greenhouse effect gases release. An interesting concept is the Small Modular Reactor (SMR) which provides passive safety, low cost of operation and installation and long cycles with duration that can reach 8 years. One of the biggest challenges for Brazil to overcome is the necessity to rethink the licensing process and the regulatory scope in order to not negatively impact the commercial costs and the innovative projects production schedule. The SMRs bring challenges to the reactor licensing process associated to the outsourcing, to the modular project´s approach, to a strong decentralization of the project activities and to the safety analysis, building and commission offsite. The article will present the Brazilian Nuclear Regulatory Body initiatives to prepare safety requirements for SMRs in harmonization with the current practices as well as cooperation among regulators, so that to provide a regulatory framework to provide for effective oversight of the nuclear power.

# Basis for Regulatory Requirements for Design and Safety Analysis of Reactor Facilities

**Speakers: H. Khouaja;**

Primary Authors: Christopher Harwood [1]; Hatem Khouaja [2]

*[1] Reactor Safety Insights Ltd., Canada; [2] CultureScapes Consulting and Training, Canada*

**Presentation Type: Oral**

**Group:** Topical Group B: Legislative and Regulatory Frameworks

**Track:** Track 7: Regulatory Considerations for SMRs (B.7)

**INDICO Abstract ID: 427**

**Abstract**

In this paper, we evaluate the current requirements and criteria for reactor design and safety analysis in being risk informed. Specifically, we focus on high-level objectives asserting that risks posed by a nuclear facility need to be comparable to the risks to which people are normally exposed; and are lower than those from alternative methods of generating power. We investigate the key metrics and elements for comparative risk assessments to establish a benchmark for “reasonable risk” through modification of the quantitative safety criteria. We emphasize the importance of comparing the reactor facility risks and benefits per unit of output against those of alternative means of producing that energy. Additionally, we identify that cumulative risks from design basis accidents are not fully captured in current deterministic safety criteria. Based on the arguments presented in this paper, we recommend the following: 1. Risk criteria should be set in terms of energy output rather than “per reactor”. 2. Risks posed by reactor facilities should be compared with those from other viable methods of electricity generation. 3. A cumulative risk target should be established to account for the overall risks from the number of postulated accidents within the design basis.

# Topical Group C: Safety, Security and Safeguards

**Participating Member States and International Organizations:**

Argentina, Azerbaijan, Belgium, Brazil, Canada, Croatia, EC JRC, Finland, France, Germany, Ghana, GIF, IAEA, India, Indonesia, Italy, OECD/NEA, Philippines, Poland, Republic of Korea, Romania, Russian Federation, Saudi Arabia, Spain, Sweden, United Kingdom, United States, WNTI

**Key Words:** security, safeguard, iaea, facility, risk, fuel, material, threat, requirement, model

## Track 8: Demonstrating SMR’s Safety Case (C.8)

# Regulatory Research Activity on Safety Analysis Methodology for Passive Safety Systems in Korea


**Speaker: J.y. Park**

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**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 8: Demonstrating SMR’s Safety Case (C.8)

**INDICO Abstract ID: 32**


**Abstract**

Recently, Small Modular Reactors (SMRs) have been actively being developed around the world and many of SMRs adopt passive safety feature as their safety systems. The nuclear industry in Korea is also developing a unique SMR called innovative SMR (iSMR) fully equipped with Passive Safety Systems. (PSSs) In light of these circumstances, KINS has launched a regulatory research project in order to develop a new safety analysis methodology given the PSS characteristics such as weak driving forces and a possibility of the functional failure. In the present paper, we would like to share our research results achieved so far, and potential improvement and its application of the safety analysis on PSS. As for the achievement, we’ve developed the reliability informed safety analysis methodology for the PSS. First, several potential factors affecting the performance and may lead to the functional failure of the PSS were identified. Then, the potential factors were incorporated into the REPAS (Reliability Evaluation of Passive Safety System) method as its “critical parameters”. Next, the REPAS method with proper failure criteria was applied and the functional failure rate of the PSS was quantified. After that, the REPAS statistical sampling sets highly contributing to the functional failure rate were single out. Finally, the REPAS critical parameters (i.e. some potential factors) included in the REPAS statistical sampling sets are identified as additional parameters for the safety analysis of the PSS. As for further improvement and possible applications of our safety analysis methodology, items such as identification of additional failure criteria of the PSS in relation to FMEA and stable long-term cooling, a

minimum safety margin to avoid the cliff-edge effect, and decision of optimal pre-service/in-service tests condition including appropriate reliability level to support the use of the PSS over the active system is scheduled to be investigated.

# HORIZON EURATOM SASPAM-SA PROJECT: MAIN IDEAS AND FIRST OUTCOMES

**Speaker: F. Mascari**

Primary Authors: Giuseppe Agnello [1]; Nikolai Bakuta [2]; Ahmed Bentaib [3]; Andrea Bersano [1]; Jeremy Bittan [2]; Laure Carenini [3]; M.e. Cazado [4]; Nabiha Chaumeix [5]; Marin Constantin [6]; Silvia De Grandis [7]; Juan Carlos De La Rosa Blul [8]; Mirco Di Giuli [9]; Stefano Ederli [1]; Florian Fichot [3]; Alain Flores [10]; Fabrizio Gabrielli [4]; Monica Garcia Martin [11]; Rositsa Gencheva [12]; Fabio Giannetti [13]; Gianmarco Grippo [1]; Dmitry Grishchenko [14]; Pavlin Groudev [12]; D. Gumenyuk [15]; Luis Herranz [11]; Mikko Ilvonen [16]; Ivan Ivanov [17]; Algirdas Kaliatka [18]; Teemu Karkela [16]; S. Kelm [19]; M. Klauck [19]; Marco Koch [20]; Julia Krieger [20]; P. Kudinov [14]; Terttaliisa Lind [21]; Pietro Maccari [1]; M. Makarenko [15]; Mateusz Malicki [21]; Fulvio Mascari [1]; Philippe Nerisson [3]; Marcello Principato [13]; E.-a. Reinecke [19]; Nils Reinke [22]; Marco Ricotti [23]; Gregor Stahlberg [20]; M. Valincius [18]; Carlos Vázquez-rodríguez [19]; Yu Yesipenko [15]; O. Zhabin [15]

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**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 8: Demonstrating SMR's Safety Case (C.8)

**INDICO Abstract ID: 83**

**Abstract**

Today, there is growing interest for light water integral PWRs (iPWR), that for their main specific features are considered one of the key technologies for the short-term nuclear technology deployment. In this framework, despite iPWRs show a reinforcement of the first three levels of DiD due to the use of passive safety systems, independent features for preventing or mitigating hypothetical Severe Accident (SA) sequences have to be included in the design. Therefore, some scenarios that could lead to SAs need to be postulated and deterministically studied along the design and the safety review process. Considering that iPWRs technology comes from the Large LWR operational experience including evolutionary modifications, in order to speed-up the European licensing/siting process of iPWRs, the Horizon Euratom SASPAM-SA (Safety analysis of SMR with

Passive Mitigation strategies – Severe Accident) project aims at investigating the applicability and transfer of the operating large LWR knowledge and know-how to iPWRs taking into account SA and EPZ European licensing needs. The project, coordinated by ENEA, started in October 2022 and involves 23 Organization. The paper aims at describing the pillars and goals of SASPAM-SA and provide the main results of the research activities performed in the first phase of the project.

# Experimental testing of a large scale water-cooled RCCS: observations and considerations for passive decay heat removal

**Speaker: D. Lisowski**

Primary Authors: Mitch Farmer [1]; Matthew Jasica [1]; Darius Lisowski [1]; Qiuping Lu [1]

*[1] Argonne National Laboratory*

**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 8: Demonstrating SMR's Safety Case (C.8)

**INDICO Abstract ID: 94**

**Abstract**

The Natural convection Shutdown heat removal Test Facility (NSTF) is a large-scale test facility constructed at Argonne built to generate validation data for passive decay heat removal systems of advanced reactors. Reflecting key features of a ½ scale, water-based, Reactor Cavity Cooling System, the facility and testing program has been on-going since 2018. Over 60 test cases, performed over a wide range of operating conditions, have been completed to study behavior and assess heat removal performance. A majority of the test cases were performed at saturation temperatures with natural circulation driven boiling flow, the operational and fluid state most prototypic to a full-scale reactor. The characteristics of natural circulation phenomena and two-phase flow can trigger complex thermal hydraulic behaviors, some of which induce unstable flow mechanisms and degraded system performance. The following paper summarizes some of the major observations and findings related to performance and stability. Specific topics include the role of inventory level on RCCS behavior, impact of changes in channel and steam discharge loss coefficients, and consequences of flow blockages. Additionally, a discussion will be included on potential impacts of boiling induced vibrations on structural components., along with recommendations for design features that may improve system stability.

# CIEMAT'S CONTRIBUTIONS TO THE RESEARCH ON SMR SAFETY AND DESIGN

**Speaker: J. Fontanet [1]**

Primary Author: Luis Herranz [2]

*[1] TBC; [2] CIEMAT*

**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 8: Demonstrating SMR's Safety Case (C.8)

**INDICO Abstract ID: 97**

**Abstract**

On the way to the decarbonization of human activities, most studies of energy scenarios to mid this century highlight the key role nuclear energy is called to play in terms of security, cost, environment, and reliability. In such a context, Small Modular Reactors (SMRs) are seen as a promising technology to be deployed in the short and medium term both in Europe and elsewhere. Regardless the local context of nuclear electricity in Spain, CIEMAT, the national centre for energy, environment and technology research, has been committed for more than a decade with research on safety of advanced reactors, with a direct projection to SMRs. CIEMAT's investigation on SMRs may be synthesized according to the different technologies addressed: HTGRs, SFRs and LWR-SMR. In addition to these studies, which describe roughly a decade of research, CIEMAT developed capabilities closely related to the water-cooled SMR technologies related to safety passive engineering features. In particular, CIEMAT developed phenomenological models of the passive containment cooling systems of mid- and large-size nuclear reactors that have inspired some of those included in the SMR designs. Nevertheless, their implementation in SMRs might need specific research. In some cases, these might mean to investigate enveloping conservative scenarios to prove their safe response under the expected conditions.

# Evolving PSA Methodologies: Towards Dynamic Reliability in SMR Passive Systems

**Speaker: M. Akmali**

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**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 8: Demonstrating SMR's Safety Case (C.8)

**INDICO Abstract ID: 99**

**Abstract**

The emergence of new nuclear reactor generations, notably Generation III+ and IV, signifies a significant advancement in the industry. These reactors aim to reduce waste and enhance safety, driven largely by startups and private entities. However, their relative immaturity and lack of testing pose challenges, especially for First of a Kind Demonstrator projects. Additionally, the introduction of unfamiliar passive safety systems raises concerns among regulatory bodies. Addressing these challenges requires innovative licensing approaches from startups and private investors to expedite approval processes. Updating traditional Probabilistic Safety Assessment methodologies is crucial in this context. This work underscores the importance of dynamic analysis in understanding and improving the reliability and safety of nuclear power plants. In response to limitations in conventional PSA, our study introduces a novel dynamic approach for the reliability assessment of Passive Isolation Condenser System in Small Modular Reactors (SMRs), a critical component in most SMRs, overcoming the limitations of traditional PSA. Leveraging the capabilities of the SAFEST tool to model and analyse dynamic fault trees, we enhance traditional PSA by incorporating dynamic aspects of passive systems like common cause failures, probabilistic functional dependencies, and failure ordering among components and systems, into failure models. This advancement facilitates a deeper understanding of the interactions and dependencies within the ICS, offering a significant improvement over static analysis methods. Our findings reveal that by expressing instant failure probabilities of components (including any external factors) as functions of parameters

like temperature, pressure, etc., a more comprehensive and accurate evaluation of reactor safety can be done. By addressing the dynamic nature of these systems, our approach allows for a more detailed and realistic representation of their operational effectiveness. The results of our study contribute to the field of nuclear safety by offering a more robust framework for the assessment of passive systems within SMRs.

# A Qualitative Study on the Reliability of TMSR500 Passive Cooling Design and Design Requirements Applicability

**Speaker: D.h. Sukarno**

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**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 8: Demonstrating SMR’s Safety Case (C.8)

**INDICO Abstract ID: 113**

**Abstract**

Almost all advanced reactor designs, including SMRs, rely on passive cooling features in the heat removal process. However, the reliability of the passive cooling system must be carefully evaluated due to the limitation of experimental data. Advanced reactor designs, specifically non-water cooled reactors, also face the challenge in terms of the existing safety design requirement applicability. In this paper, a qualitative study on the reliability of the TMSR500 passive cooling design has been performed. The applicability of the existing safety design requirements to the TMSR500 cooling design is also discussed here. The reliability of the TMSR500 passive cooling system is studied qualitatively through four steps: 1) Identification of parameters affecting the operation; 2) Identification of key parameters which may cause the failure; 3) Root diagnosis to find deviation of key parameters for causing system failure (using fault trees); and 4) Evaluation of system reliability. The result of the study informs that the flow resistance especially which disturbs the access to the ultimate heat sink (environmental air), such as air intake and basement pipe outlet logging, becomes the key parameter in causing the system failures. The quantitative value of passive cooling system reliability can be achieved if the failure rate of each component is known. For conservative analysis, the cooling capability estimation in the absence of passive air cooling is needed. Using simple analytical calculation supported by ORIGEN for decay heat calculation, the availability of basement water as the time function can be estimated conservatively. The applicability of reactor coolant system design requirements, listed on Requirements 47 – 52 of the IAEA Safety Standard No. SSR-2/1 (Rev. 1), to the TMSR500 cooling system

design is also discussed here. Supported by the IAEA Safety Report Series No. 123, the identified gap will be more elaborated specifically on the TMSR cooling system design.

# NUCLEAR SAFETY AND DEFENCE IN DEPTH IN CAREM25

**Speaker: M.o. Giménez**

Primary Author: Marcelo Gimenez [1]

Co-Authors: David Alfredo Quiroga [1]; Mariela Grinberg [1]; Pablo Zanocco [1]

*[1] CNEA*

**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 8: Demonstrating SMR's Safety Case (C.8)

**INDICO Abstract ID: 120**

**Abstract**

This work discusses the technological strategy adopted in CAREM25 to fulfil the Principle of Defense in Depth and its assessment by Deterministic and Probabilistic Safety Analysis (DSA, PSA). The strategy defined for levels 3A and 3B is based on two stages and using passive and active systems. Moreover, the implemented DiD strategy is the basis for setting graduated criteria for safety functions categorization and structures, systems and components (SSCs) classes allocation, allowing to establish coherent design requirements. Safety classification process is executed beginning from the Fundamental Safety Functions and, using attributes, Low Level Safety Functions (LLSFs) including monitoring ones were constructed for each DiD levels and stages. Next, Safety Functional Groups -set of SSCs that fulfill a function- were identified for each LLSF. Finally, categories and classes were allocated. PSA and DSA were used to support this process, evaluating the SSCs relative importance. Moreover, both methodologies were used to provide design feedback for DiD Levels 2 and 3, evaluating different strategies to cope with the postulated initiating events. Findings are presented. This integral approach based on DiD has facilitated engineering development and the licensing process by providing a comprehensive assessment of systems design and a balanced integration into the plant

# NAAREA's XAMR® safety approach

**Speaker: T. Kooyman**

Primary Authors: Khalida El Ouarghi [1]; Timothée Kooyman [1]

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**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 8: Demonstrating SMR's Safety Case (C.8)

**INDICO Abstract ID: 193**

**Abstract**

NAAREA is a French startup currently designing a 80 MWth fast modular micro-reactor fueled with a molten chloride. No such reactor has been designed or operated in the past, the available experience return on molten salt reactors being limited to fluoride based thermal reactors built at ORNL in the fifties and sixties. The current safety framework which has capitalized on several decades of PWR operation is not readily adapted to molten-salt reactors, and the solutions which were implemented in the sixties are not adequate today. Furthermore, molten salt reactor design is strongly versatile due to the very nature of the fuel used and the maturity of the various designs currently under work is not enough to outline a general safety approach. Thus, this paper presents the approach chosen by NAAREA for its safety case, and especially: * The main differences compared to standard PWR safety approach. * The design options selected to ensure decay heat removal, reactivity management and containment of radionuclides. * The severe accident definition selected by NAAREA and its consequences on the reactor design.

# Flange Management Approach for Reliable SMR Reactor Vessel Integrity

**Speaker: G. Briggs**

Primary Author: Gary Briggs [1]

Co-Authors: Martin Coulthard [1]; Ian Craven [1]

*[1] James Walker*

**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 8: Demonstrating SMR’s Safety Case (C.8)

**INDICO Abstract ID: 204**

**Abstract**

Small modular reactor (SMR) pressure vessels depend greatly on the integrity of a bolted flange assembly. Whether subject to periodic refuelling cycles or through-life secure closure, the reliability and security of Reactor Vessel and ancillary containment will determine the overall safety of an SMR. This paper proposes the application of a highly proven approach from heat exchanger integrity technology through calculation, to enhance the safety of SMR Reactor Pressure Vessels. The “Flange Management” approach utilises holistic appreciation of flange design & calculation, seal specification and accurate bolt loading in the context of each specific application. Previous technology in nuclear has used varying methods, such as hot bolting, hydraulic tensioning and torque measurement. Whilst these have proven acceptable in some instances, the utilisation of Flange Management has emerged within nuclear structural inspection methodologies and offers a promising solution for the SMR community; reducing uncertainty, reducing time and reducing exposure to active environments within a plant. These integral elements of safety are achieved through practical elimination of uncertainty in design and an offer of simplification drawing on highly proven techniques.

# Analysis of DEC-A sequences in a NuScale-like SMR considering ATF fuel performance using the system code TRACE

**Speaker: J. Sanchez-torrijos**

Primary Author: Jorge Sanchez-torrijos [1]

Co-Authors: Yago Martinez [2]; Amparo Soler [1]; Emilio Castro [2]; Cesar Queral [2]

*[1] NFQ ADVISORY SERVICES; [2] Technical University Of Madrid*

**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 8: Demonstrating SMR's Safety Case (C.8)

**INDICO Abstract ID: 255**

**Abstract**

This analysis assesses the benefits derived from implementing FeCrAl cladding material under DEC-A sequence conditions in a NuScale-like Small Modular Reactor, utilizing the TRACE system code, in comparison to the conventional Zr alloy fuel rod case. In collaboration between NFOQUE ADVISORY SERVICES S.L. (NFQ) and the research group from the Technical University of Madrid (UPM), an in-house version of the TRACE code in which FeCrAl material properties and behavioral models code has been implemented allowing to incorporate FeCrAl cladding performance into the simulations. The chosen accidental scenarios involve LOCA sequences combined with various failures in the Reactor Recirculation Valves, Reactor Vent Valves, and the Control Volume and Chemical System. The results demonstrate an increase in the available times and a general improvement in the behavior of fuel rods within the selected ATF concept, as opposed to the case where conventional Zr-alloy fuel rods are considered.

# Passive Safety System and Safety Demonstration of innovative Small Modular Reactor (i-SMR)

**Speaker: S. Lim**

Primary Author: Sang-gyu Lim [1]

Co-Authors: Jong Cheon [1]; Sun Heo [1]; Han Gon Kim [1]; Tae Cheol Park [1]

*[1] i-SMR Development Agency*

**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 8: Demonstrating SMR's Safety Case (C.8)

**INDICO Abstract ID: 273**

**Abstract**

In order to respond to the global climate crisis and supply sustainable clean energy, the Republic of Korea has developing a new SMR named innovative SMR(i-SMR). The safety goals of the i-SMR are that a core damage frequency (CDF) is less than 10-E9 and a large early release frequency (LERF) is less than 10-E10. To achieve these safety goals, a passive system design is applied and a non-safety active system design is applied to back it up. The safety systems of i-SMR enable the emergency planning zone (EPZ) to be within the site boundary, which will be designed to practically eliminate the need for public evacuation during an accident. This paper discusses the design characteristics of the passive system adopted by the innovative SMR. The safety system of the innovative SMR consists of a passive emergency core cooling system to respond to LOCA accidents, a passive auxiliary feedwater system to respond to non-LOCA accidents, and a passive containment cooling system to cool down the steel containment vessel. Also, this paper deals with examples of safety analysis results for the performance of those systems during the accidents. Lastly, a demonstration plan of the safety system through separated effect tests and integral effect tests is described.

# A probabilistic safety analysis of the first level safety of small modular reactors on the example of the SHELF-M reactor facility

**Speaker: P. Elistratov**

Primary Authors: Stepan Andreev [1]; Pavel Elistratov; Gregory Pokidov [1]; Eugeniy Shiverskiy [1]

*[1] JSC "NIKIET"*

**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 8: Demonstrating SMR’s Safety Case (C.8)

**INDICO Abstract ID: 280**

## Abstract

The current report is dedicated to the issues of probabilistic safety analysis of the first level safety of small modular reactors on the example of a low-power nuclear power plant with a SHELF-M reactor facility. Probabilistic safety analyses were conducted to determine the possibility of accident pathways and final outcomes, including the possibility of severe accidents. In this report, the probability of a severe accident for the small modular reactor used in the SHELF-M reactor facility has been evaluated by considering the main technical concepts used in the SHELF-M reactor facility and the structural components of the reactor plant, a description of the main and auxiliary systems of the reactor unit has been provided. And the dominant contributors to the probability of a severe accident in case of exceeding the maximum design limits for the fuel and fuel cladding temperature have been presented in the report. Based on the designed PSA Level-1 model, preliminary conservative calculations were carried out to identify dominant risk contributors, to evaluate sensitivity in relation to major design decisions and to elaborate recommendations to improve reliability at the system level and safety of the plant overall. The following initial events were shown to dominate the risk indicators: - leading to loss of heat transfer medium by the first circuit; - leading to a disruption of heat removal by the second circuit. At the system and element level, the dominant contributors to plant non-reliability are: the hydraulic accumulator of the hydraulic distributor, the fittings of the feed water system, emergency core-cooling systems (ECCS), the check valves of the feed water system, and the valves of the

equipment cooling system. Implementation of the recommendations proposed based on the PSA-1 results into the SHELF-M design allowed to bring its probabilistic safety indicators in compliance with the regulatory requirements.

# Challenges and Opportunities in Developing a Safety Case for Small Modular Reactors: The Ghanaian Perspective

**Speaker: F. Ameyaw**

Primary Author: Felix Ameyaw [1]

Co-Author: Joshua Gbinu [1]

*[1] Ghana Atomic Energy Commission*

**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 8: Demonstrating SMR’s Safety Case (C.8)

**INDICO Abstract ID: 283**

**Abstract**

This review paper examines the safety objectives and application of defence-in-depth to Small Modular Reactors (SMRs) in Ghana, focusing on inherent and passive safety features, design simplification, integration, and modularity. It explores safety challenges and opportunities specific to SMRs, including severe accident mitigation, internal and external hazard considerations, and fuel and core safety. The paper also discusses materials and chemistry safety implications, risk-informed approaches for SMRs, and novel deployment models. It emphasizes the need for a robust safety case to address these challenges, highlighting the importance of leadership and management of safety in the context of Ghana's nuclear power program. The novelty of this paper lies In its comprehensive examination of the safety objectives and application of defence-in-depth to SMRs in Ghana, focusing on specific challenges and opportunities unique to the country’s nuclear power program. It provides practical insights into addressing these challenges, enhancing the safety and success of SMR deployment in Ghana.The conclusions drawn from this review paper provide insights into the practical implementation of safety measures for SMRs in Ghana, contributing to the overall safety and success of the country’s nuclear power development. Keywords: Small Modular Reactors (SMRs), Safety Case, Ghana, Nuclear Power, Challenges and Opportunities

# Small Modular Reactor Multi-Module PSA

**Speaker: M. Obergfell [1]**

Primary Author: Manuel Obergfell [2]

Co-Author: Florian Berchtold [2]

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**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 8: Demonstrating SMR's Safety Case (C.8)

**INDICO Abstract ID: 316**

**Abstract**

Nuclear power plants (NPPs) with advanced reactor technologies, particularly small modular reactors (SMRs) are planned to be built in various countries worldwide. Due to the much lower power output of these reactor types in comparison to operating NPP units, the plants with SMRs are intended to be realized by multiple modules of the same type at a given site. Based on the type of the multi-module concept, the different SMR modules may share some systems, structures and components (SSC, e.g., a joint building, or electricity supply) and/or a common team of operators. As an example, the NuScale VOYGR™-type SMR is developed to share SSC for up to twelve modules. For analysing the risk of multiple modules at a common site, GRS has developed a multi-module Level 1 PSA for a VOYGR™ SMR plant applying the commercially available PSA code RiskSpectrum®. The model enables the analyst to compare the risk from a single module to that of multiple, up to twelve identical modules located in the same building, sharing several SSC and the operators´ team. The manufacturer´s PSA of NuScale has been modified by an own analysis of initiating events (i.e., common cause initiators (CCIs) affecting multiple modules) and applying reliability data for systems and components from the German operating experience regarding single and/or common cause failures (CCFs). As a result, the core damage frequencies (CDFs) for a hypothetic site with only a single SMR single module site and with twelve modules have been determined and compared. Multi-module cut sets with an important contribution to the overall risk are identified. Inter-module CCFs and human failures have been observed to be the important risk contributors. The analysis of significant contributors to the inter-module risk appears to be beneficial for quantifying the main cut sets and the safety balance of the reactor concept.

# On some safety aspects in Small Modular Reactors

**Speaker: P. Min**

Primary Author: Petre Min [1]

Co-Authors: Dan Serbanescu; Bogdan Vamanu

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**Presentation Type: Poster**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 8: Demonstrating SMR's Safety Case (C.8)

**INDICO Abstract ID: 327**

## Abstract

The development of the new generation of nuclear power reactors is a result of continuous improvement from efficiency and safety perspectives. Even if safety criteria are very important, the nuclear reactor technology is targeting a development area of an optimum between them and the performance criteria. As there is a large set of new types of Small and Modular Reactors (SMR), the evaluation of the benefits and challenges of each of them is very important in the strategic development of SMR. The paper is presenting an approach from two perspectives on the criteria to be considered in the SMR development: 1. Exegetics, i.e. evaluation of the impact of the reactor from the maximum possible energy to be used in the existing thermodynamic conditions. 2. Risk level, i.e. the evaluation of the risks as defined in the traditional existing safety analyses. Exergy balance in nuclear power plants also indicates the plant risk map, including the impact on the environment for the whole lifecycle. The methodology of the exergy balance and risk analyses is presented for three cases of SMR types are areas of potential risk: water, gas and molten sault cooled.

# Assessment of the Safety Design Features of Small Modular Reactors with existing demonstration plants using Reactor Technology Assessment (RTA)

**Speaker: U.a. Bautista**

Primary Author: Unico Bautista [1]

Co-Authors: Mark Gino Aliperio [2]; Alvie Asuncion-astronomo [3]; Rinlee Butch Cervera [4]; Neil Raymund Guillermo [3]

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**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 8: Demonstrating SMR's Safety Case (C.8)

**INDICO Abstract ID: 337**

**Abstract**

Small Modular Reactors (SMRs) represent a promising solution for nuclear power generation, offering compactness and flexibility with capacities ranging from 10 to 300 MWe. This research aims to narrow the existing knowledge gap in the safety of SMRs by conducting a preliminary analysis, focusing on their safety design features, particularly those of operating demonstration plants. Building upon our prior technical analysis, which focuses on SMRs with operational demonstration plants, this study delves into the safety design features of these reactors with the aim of assessing their potential deployment in the Philippines. Through a Reactor Technology Assessment (RTA), the safety design aspects of shortlisted SMR designs are examined, with a focus on their active and passive safety systems as reported in the reactor databases of the International Atomic Energy Agency (IAEA). Thus, this study will provide valuable insights for decision-makers in the Philippines' nuclear power program.

# Aerosol evolution in a typical SMR containment under hypothetical accidental conditions

**Speaker: S. Anand**

Primary Authors: Srinivasan Anand [1]; Jayant Krishan [2]; Mukund Kulkarni [1]

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**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 8: Demonstrating SMR's Safety Case (C.8)

**INDICO Abstract ID: 356**

**Abstract**

Enhancing safety measures for Small Modular Reactors (SMRs) necessitates a comprehensive understanding of aerosol behavior within containment structures during accidental conditions. This study employs the NAUA aerosol dynamics code (Bunz et al., 1987) to investigate the dynamic evolution of aerosols in a typical SMR containment (surface area to volume ratio = 0.022 cm$^{-1}$). Assuming a large-scale release of 2.2 g/s for 1-h in a containment volume of 3.5E+09 cm$^3$, simulations are conducted for 10$^4$ minutes. Results, depicted in Fig. 1, reveal gravitational settling as the predominant deposition process, followed by diffusional deposition, while the contribution of diffusio-phoretic deposition is negligible. However, NAUA does not account for thermophoretic deposition, highlighting a need for future consideration. The study focuses on elucidating the effects of various accident scenarios, such as loss-of-coolant incidents, on aerosol distribution and concentration profiles over time. Ongoing research aims to incorporate more realistic input conditions and additional physical processes into the numerical code to improve the prediction of aerosol evolution and radioactive source term during postulated accidental conditions. Insights gained from this investigation can inform the design of emergency response strategies and optimize containment systems for SMRs, thereby advancing nuclear safety engineering. ![Fig. 1: Aerosol mass deposition on the containment surfaces][1] Reference Bunz, H., Kyoro, M. and Schoeck, W. (1987) NAUA Mod 5 and Mod 5-M, Zwei Computerprogramme zur Berechung des Aerosolverhaltens im Containmentsystem eines LWR nach einem Kernschmelzunfall. KfK-4278, Kernforschungszentrum, Karlsruhe. [1]: http://home/internet-user/Desktop/SMR_Aerosol_contain.png

# Accelerating international cooperation on SMR safety research: the OECD Nuclear Energy Agency (NEA) working group on the analysis and management of accidents (WGAMA)

**Speaker: H. Nakamura**

Primary Authors: Martina Adorni (oecd Nuclear Energy Agency) [1]; Ahmed Bentaib [2]; Fulvio Mascari [3]; Hideo Nakamura [4]; Pierre Ruyer [2]

*[1] OECD Nuclear Energy Agency (NEA); [2] IRSN; [3] ENEA; [4] Japan Atomic Energy Agency*

**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 8: Demonstrating SMR's Safety Case (C.8)

**INDICO Abstract ID: 362**

### Abstract

The Working Group on the Analysis and Management of Accidents (WGAMA) addresses OECD Nuclear Energy Agency (NEA) activities related to potential design-basis and beyond design-basis accidents in nuclear reactors and related technologies. The WGAMA addressed safety aspects of existing nuclear reactors and related technologies as well as emerging challenges of evolutionary and innovative reactor designs and nuclear technologies, including Small Modular Reactors (SMRs). The group initiated the review of its past activities in the fields of thermal-hydraulics, computational fluid dynamics (CFD) and severe accidents (SAs) to assess their applicability to SMR and define what extra work will be needed. In particular, subjects of high priority were identified as reliability assessment of passive system, modelling innovation in CFD, severe accident management (SAM) countermeasures, advanced measurement methods and instrumentation, and modelling robustness of safety analysis codes. Furthermore, starting in 1993, the NEA initiated development of CSNI Code Validation matrix (CCVM) that gathers up-to-date the largest set of test data in matrix for various technology and reactor design including relevant phenomena dominating different types of accidents and transients; phenomena occurrence vs experimental facilities; and suitability of the experimental facilities, thus databases, for code assessment. The construction of this internationally agreed CCVM for safety codes is great achievement

to systematically collect the best sets of openly available test data for code validation, assessment, and improvement, including quantitative assessment of uncertainties in the modeling of individual phenomena by the codes. To support validation of the codes to be used for safety assessment of SMR significant efforts will be needed to update the current CCVM and extend it to cover phenomena, experiments, and facilities specific or even unique to AT-SMR designs. This paper aims at summarizing the recent achievements of the WGAMA.

# Coupled thermal-hydraulic and neutronic deterministic safety analysis for the HTGR SMR research demonstrator HTGR-POLA.

**Speaker: M. Skrzypek**

Primary Author: Maciej Skrzypek [1]

Co-Authors: Eleonora Skrzypek [1]; Dominik Muszyński [1]

*[1] National Centre for Nuclear Research*

**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 8: Demonstrating SMR's Safety Case (C.8)

**INDICO Abstract ID: 373**

## Abstract

Poland facing energy transformation considers large-scale PWRs, as well as SMRs. SMRs can be seen as a potential electricity supply and beyond, i.e. district heating, industrial process heat, and for hydrogen production. For past few years National Centre for Nuclear Research, Poland (NCBJ) has been involved in several High Temperature Gas-cooled Reactor projects: national (Gospostrateg-HTR, HTR-MEiN) and European (Gemini Plus, Gemini for Zero Emission). Consequently, the small-scale, prismatic type, research HTGR of 30 MWt - named HTGR-POLA, is considered to be built at the NCBJ's site. Its main mission is to serve as a demonstrator of HTGR technology for Polish industry. In this paper, for the reference HTGR-POLA plant design, the capability of coupled neutronics/thermal-hydraulics (N/TH), and its impact on the reactor safety performance during selected Design Basis Accidents (DBA) will be investigated. The introduced capability of a coupled N/TH phenomena for the reactor core over the whole fuel cycle is a promising method, due to its possibility of approximation and identification of the most relevant safety issues without the need for introduction of over conservative assumptions. The results of the calculations for the coupled Serpent-MELCOR 2.2. codes will be presented, from the selected accident groups representing various types of Postulated Initiating Event (PIE) for HTGRs. The calculations performed, were accompanied by the sensitivity study of the chosen parameters, evaluated as most impactful on the safety and design acceptance criteria established (the Safety Systems and Components - SSCs design parameters and Polish high level requirements). The

presented results were a supporting means for the Probablistic Safety Analysis of the HTGR-POLA reactor for the assessment of the accident consequences and considerable part of the Preliminary Safety Analysis Report (PSAR), which is a requirement included in the legal framework of newly built Nuclear Power Plants (NPPs) and research reactors in Poland.

# Context of Single Failure Criterion (SFC) Application for Small Modular Reactor (SMR)

**Speaker: I. Basic**

Primary Authors: Ivica Bašić [1]; Ivan Vrbanić [1]

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**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 8: Demonstrating SMR's Safety Case (C.8)

**INDICO Abstract ID: 414**

**Abstract**

The Single Failure Criterion (SFC) ensures reliable performance of safety systems in nuclear power plants in response to design basis initiating events. The SFC, basically, requires that the system must be capable of performing its task in the presence of any single failure. The capability of a system to perform its design function in the presence of a single failure could be threatened by a common cause failure such as a fire, flood, or human intervention or by any other cause with potential to induce multiple failures. When applied to plant's response to a postulated design-basis initiating event, the SFC usually represents a requirement that particular safety system performs its safety functions as designed under the conditions which can include:  All failures caused by a single failure;  All identifiable but non-detectable failures, including those in the non-tested components;  All failures and spurious system actions that cause (or are caused by) the postulated event. The paper provides an updated overview of the regulatory design requirements for new reactors and small modular reactors addressing Single Failure Criterion (SFC) in accordance to international best-practices, particularly considering the SCF relation to in-service testing, maintenance, repair, inspection and monitoring of systems, structures and components important to safety. The paper discusses the comparison of the current SFC requirements and guidelines published by the IAEA, WENRA, EUR and nuclear regulators in the United States, United Kingdom, Russia, Korea, Japan, China and Finland. Also, paper addresses the application of SFC requirements in design; considerations for testing, maintenance, repair, inspection and monitoring; allowable equipment outage times; exemptions to SFC requirements; and analysis for SFC application to two-, three- and four-train systems and applications for small and modular reactors.

# A Method for Sizing Emergency Planning Zones around Small Modular Reactors and New Reactor Technologies

**Speaker: D. Hummel**

Primary Author: David Hummel [1]

Co-Authors: Luke Lebel [1]; John Cui [1]; Sohan Chouhan [1]

*[1] Canadian Nuclear Laboratories*

**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 9: Emergency Preparedness and Response for SMRs (C.9)

**INDICO Abstract ID: 43**

**Abstract**

Off-site emergency protective actions are the fifth and final level of defence in depth against the consequences of nuclear accidents. The area around the site where pre-planned precautionary or urgent protective actions are ready to be taken in the event of an emergency is the emergency planning zone (EPZ). Stakeholders for small modular reactor (SMR) and advanced reactor technologies have advocated that, considering the risks relative to contemporary large nuclear power plants, the EPZ around SMRs may be reduced in size or outright eliminated. However, past investigations have revealed lack of clarity or uncertainty in the technical criteria that determine the necessary EPZ size. To that end, Canadian Nuclear Laboratories has been developing a decision-making framework to identify the events that should be considered in the off-site planning basis and what is the necessary extent of the urgent protective action planning zone. The proposed method is based on some principals of Level 3 probabilistic safety assessment as well as an evaluation of public health risks in units of adjusted life years. This study develops the method and demonstrates its application with a simplified case study.

# Regulatory Recommendation in Determining Adequate Emergency Planning Zone for Multi Module Small Modular Reactor in Indonesia

**Speaker: M. R. Harahap**

Primary Author: Muhammad Rifqi Harahap [1]

Co-Authors: Bintoro Aji [2]; Rahmat Harianto [3]

*[1] BAPETEN - Indonesia Nuclear Energy Regulatory Agency; [2] BAPETEN; [3] INDONESIA NUCLEAR ENERGY REGULATORY AGENCY*

**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 9: Emergency Preparedness and Response for SMRs (C.9)

**INDICO Abstract ID: 111**

**Abstract**

In recent developments, nuclear reactor design has adopted a multi-module design for small modular reactor (SMR). In this design, a single reactor unit consists of several uniform reactor modules that are placed in an adjacent location inside the reactor building with a shared structure, system, and component (SSC) between induvidual modules. This configuration causes some deviation in the safety provisions that have been established for conventional reactor. Therefore, Indonesia conducted identification and review for existing safety provisions for determining the emergency planning zone (EPZ) for power reactors. Identification and review are conducted by describing and reviewing related safety provision for power reactors in Indonesia, applicable international standards, and safety provisions from other international regulatory bodies. From the review, it was discovered that independency between individual modules is the key parameter to determine the multi-module SMR design source term and EPZ acceptance criteria. BAPETEN, as the Indonesian regulatory body, needs to ensure that there is no interconnection between individual modules. This paper also recommend BAPETEN to implement a risk-informed, performance-based approach as an additional tool to ensure that the EPZ determination also credited the technological advancement of SMR without undermining the risk level.

# Determining Emergency Planning Zone size through JRODOS calculated radiation dose consequences in High-Temperature Gas-Cooled Reactors

**Speaker: P. Kopka**

Primary Authors: Piotr Kopka [1]; Aleksej Kaszko [1]; Eleonora Skrzypek [1]; Maciej Skrzypek [1]

*[1] National Centre for Nuclear Research*

**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 9: Emergency Preparedness and Response for SMRs (C.9)

**INDICO Abstract ID: 214**

**Abstract**

The conceptual design of the High-Temperature Gas-Cooled Reactor (HTGR) research reactor was developed by the team at the Division of Nuclear Energy and Environmental Analysis of the National Centre for Nuclear Research (NCBJ). Emergency Preparedness and Response (EPR) analysis is essential, leading to the designation of an Emergency Planning Zone (EPZ), which is crucial for advancing the project. Due to characteristics like the effective heat removal by HTGR cores and the significant reduction of dust-containing sorbed fission products by TRISO particles, the EPZ size is reduced. These zones are established based on safety analysis results, considering potential emergency scenarios with the worst possible consequences and probability of occurrence equal to or greater than once in 10^7 years calculated using severe accident code (MELCOR). Radiological analysis, utilizing JRODOS, was conducted for various accident scenarios (e.g., D-LOFC), incorporating a range of weather scenarios. The analysis demonstrated that the limited radionuclide inventory available for release and specific security-enhancing rector design inherently mitigates the dose consequences. Statistical analyses were performed for the surrounding NCBJ institute area, highlighting the distribution and risk factors for populated areas. The observed decrease in consequences indicates that smaller EPZs could be viable without raising risks to public safety.

# How Artificial Intelligence and Small Modular Reactors Will Power Emergency Preparedness and Response


**Speaker: R. Rockabrand**

Primary Author: Ryan Rockabrand [1]

*[1] United States National Nuclear Security Administration*


**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 9: Emergency Preparedness and Response for SMRs (C.9)

**INDICO Abstract ID: 279**


**Abstract**

The purpose of this research is to enhance requirements for personnel considering Artificial Intelligence (AI) capabilities during the adoption of Small Modular Reactors (SMR) in the context of nuclear Emergency Preparedness and Response (EPR) activities. The goal is to understand how AI might integrate into the emergency response organizations for SMR deployments to improve decision-making and crisis management strategies. Approaches to EPR requirements must undergo a profound transformation to adequately address the complex challenges as well as opportunities presented by the deployment of SMRs and AI by specifically evolving current frameworks and response plans. In the realm of SMR deployments, AI may serve as a crucial ally in enhancing EPR measures while at the same time introducing new considerations including: • Remote vs. on-site/In-the-vicinity operations • Staffing plans, qualifications, and training including SMR engineering expertise • Scenario simulations to include digital twins of facilities • Responding to communication challenges for remote operations centers • Management of SMR maintenance and modifications

# Benchmarking Near-field Radionuclide Dispersion with CFD and Gaussian Model

**Speaker: S. Lal**

Primary Author: Sreeyuth Lal [1]

Co-Authors: Aneesh John [1]; Luke Lebel [1]

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**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 9: Emergency Preparedness and Response for SMRs (C.9)

**INDICO Abstract ID: 314**

**Abstract**

There is increasing interest in locating small modular reactors (SMRs) closer to potential end users for industrial or district heating applications, which is making it more important to understand the near-field atmospheric dispersion behaviour of routine or accidental radionuclide emissions. Traditional codes have known limitations in predicting nearfield dispersion due to the heavy influence of the size and nature of the built-up features as well as the topology of the near-field area. This work addresses these limitations and complements existing practices by using high-fidelity computational fluid dynamics (CFD) modeling for a realistic assessment of near-field radionuclide dispersion on a complex site. The terrain and building geometries of the chosen site are reconstructed from detailed aerial scans. The CFD results are compared to those from RASCAL, a consequence analysis code which uses simplified Gaussian dispersion models and empirical parametrizations of building wake effects to calculate near-field dispersion. Finally, a discussion on the use of these two approaches, both individually and complementarily, for calculating radiological consequences of postulated SMR accidents is presented.

# Release-Category-Based Emergency Planning Zone Calculation Applied to a Light-Water Small Modular Reactor Design

**Speaker: A. Guglielmelli [1]**

Primary Authors: Juan Carlos De La Rosa Blul [2]; Antonio Guglielmelli [2]

*[1] TBC; [2] European Commission Joint Research Centre*

**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 9: Emergency Preparedness and Response for SMRs (C.9)

**INDICO Abstract ID: 357**

## Abstract

Emergency Planning Zones (EPZs) are areas around a nuclear or radiological facility where arrangements to protect the public in case of nuclear emergency are planned. This paper presents and discusses the calculation of EPZ distances based on a novel approach for the analytical identification and classification of the source term for accidents with total or partial fuel damage. This approach is deterministic in so far as it starts with the postulation of a set of Plant Damage States (PDSs, rather than frequency-based). This approach is complemented by a methodological application for the analysis of the accident progression based on the facility response assessment, similar to the logic behind Containment Event Trees. Such extension to the deterministic postulation of PDSs stems from the recognition that deterministic approaches may lead to incompleteness in the selection of accident scenarios due to strongly relying on expert judgement. The case study applies to a 300 MWe integral Pressurized Water Reactor SMR, which is one of the two selected designs by the European-Union-funded SASPAM-SA project.

## Track 10: Safety, Security and Safeguards Interfaces related to SMRs (C.10)

# Recommendations for Design-Stage Safety and Security Probabilistic Risk Assessment Co-Development


**Speaker: A. Huning**

Primary Authors: Alexander Huning [1]; Steve Reed [1]

*[1] Oak Ridge National Laboratory*


**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 10: Safety, Security and Safeguards Interfaces related to SMRs (C.10)

**INDICO Abstract ID: 59**


**Abstract**

As many advanced and small modular reactor developers are entering the licensing process and looking to expand their commercial offerings internationally, nuclear security is a critical but often overlooked element as part of the design process. Probabilistic risk assessments are being used to support risk-informed safety assessments but have not gained significant awareness as highly effective multi-purpose tools for a broad range of nuclear security applications. Designing a plant protection system, and other barriers which may serve a security function, after a conceptual or basic design phase may lead to higher total security costs and/or redesign of other buildings, structures, system placements or components. This motivates for a “security-by-design” approach. Probabilistic risk assessments can aid in this approach by supporting the identification and quantifying the risk importance of various target sets and assessing the impact or consequences of security scenarios which will lead to an improved protection strategy that adequately addresses the risks due to all design basis threats. However, there are many fundamental differences between a probabilistic risk assessment used for safety and used for security events (i.e., sabotage events). When these differences are identified and included in the development processes, a safety and security probabilistic risk assessment can be effectively constructed in tandem without significantly more burden placed on the design and analysis teams. Using traditional probabilistic risk assessment elements as a

guide, this paper will provide technical recommendations for the integration of security and plant protection features into a safety probabilistic risk assessment, which can be easily turned on or off depending on the application. The goal is to create an effective and integrated safety and security probabilistic risk assessment model without having separate models leading to version control and consistency problems to which design phase risk assessments are vulnerable.

# Researching floating nuclear reactors from a 3S perspective

**Speaker: S. Grape**

Primary Author: Sophie Grape [1]

Co-Authors: Erik Branger [1]; Henrik Josefsson [1]; Vaibhav Mishra [1]; Debora Trombetta [2]

*[1] Uppsala University; [2] KTH*

**Presentation Type: Poster**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 10: Safety, Security and Safeguards Interfaces related to SMRs (C.10)

**INDICO Abstract ID: 133**

**Abstract**

Recently, an interdisciplinary research project on floating nuclear reactors was initiated. The overall goal of the project is to perform research related to the safety, safeguards and security of such systems, and to support Safeguards and Security by Design. The project, which will run for 3.5 years, will investigate challenges associated with equipping ships with nuclear reactors. Such challenges could be a concern for e.g., nuclear infrastructure and transports of nuclear material, technical research on different reactor concept and their intended operation; and research related to legal and regulatory issues associated with the ownership/licensing, operation and maintenance of the ships and reactors. The project is divided into three phrases. The first phase includes an overview of floating reactor concepts, identification of common challenges, assessments of to what extent existing safeguards and security practices can be applied, and the identification of gaps for further research. In the second phase, proliferation resistance studies and nuclear material assessments will be performed, together with research on the legal frameworks. In the third phase, recommendations on regulatory pathways for ship-based reactors will be presented, together with suggestions concerning physical protection and the verification of nuclear material for safeguards purposes. In this paper we will describe the project in more detail, and elaborate on results from the first months of execution.

# Title: 3Ss Approach for advanced SMRs designs in Belgium

**Speaker: I. Sanda**

Primary Authors: Irina Sanda [1]; Fernand Vermeersch [1]

*[1] SCK CEN*

**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 10: Safety, Security and Safeguards Interfaces related to SMRs (C.10)

**INDICO Abstract ID: 143**

**Abstract**

An integrated approach to the implementation of safety, security and safeguards (3Ss) by design is an important concept for the new and advanced reactor designs, and it is essential for an SMR, at an early design stage, in order to optimize its size and performance. SCK CEN is starting, together with partners, a SMR-LFR project, looking at constructing a demonstrator for the lead cooled technology. In Belgium, the law stipulates that : "The operator of a class I establishment is required to apply the obligations imposed on it by regulations in the areas of "Safety, Security and Safeguards" in a coordinated, consistent, effective and efficient way, in the field, while taking into account the different interfaces." The paper will focus on the approach to 3Ss by design, at an early stage of the reactor design, in order to optimize the implementation of requirements and properly address all the interfaces, including aspects related to radiation protection of the worker, the public and the environment. An important focus will be put on the management of 3Ss in design and normal operation, as the first lines of defense against initiating events, hazards and threats.

# Approaches for Comprehensive Safety and Digital Risk Management for Advanced Nuclear Technology and Small Modular Reactors


**Speaker: J. Mahanes**

Primary Authors: Robert Anderson [1]; Mitchell Hewes [2]; Joseph Mahanes; Michael St. John-green

*[1] Idaho National Laboratory; [2] IAEA*


**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 10: Safety, Security and Safeguards Interfaces related to SMRs (C.10)

**INDICO Abstract ID: 154**


**Abstract**

Small Modular Reactor designs are likely to rely on complex digital technology novel to nuclear industry applications while also leveraging passive systems and safety design simplification. The result of current approaches may lead to a safety-driven system design that lacks demonstrated robustness in the event of cyber-attacks against its digital equipment. Information and computer security should be an integral part of engineering and operational processes. Current safety and security thinking does not encourage sufficient interaction. Teams are often separate and management structures reinforce this separation. This paper provides a case for cybersecurity related safety and security requirements to be considered together throughout design, licensing, and operation. Safety envelope boundaries may be expressed using many variables and suitably defined system theoretic models can be used to alert whether due to faults, failures or malicious action. This provides a unifying “top down” framework for digital systems safety and and approaches supporting and implementing safety and security requirements. This paper will identify existing work supporting this closer safety/cybersecurity relationship. However, new tools, techniques, and ways of working need developing to enable SMR designers, regulators and operators to employ complex digital technology in a way that remains both safe and secure.

# Identifying sabotage risks and adversarial Threats to passive Decay heat removal systems in advanced nuclear reactors

**Speaker: D. Lisowski**

Primary Authors: Matthew Bucknor [1]; Scott Ferrara [2]; David Grabaskas [1]; Alex Hunning [3]; Darius Lisowski [1]; Douglas Osborn [4]; Curtis Smith [2]

*[1] Argonne National Laboratory; [2] Idaho National Laboratory; [3] Oak Ridge National Laboratory; [4] Sandia National Laboratories*

**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 10: Safety, Security and Safeguards Interfaces related to SMRs (C.10)

**INDICO Abstract ID: 212**

**Abstract**

Advanced reactors, including aSMR, GenIV, etc. aim to enhance reliability by incorporating passive safety systems into their plant design. These systems leverage passive methods to provide a high level of reliability for removing decay heat from the reactor core to achieve safe shutdown conditions or other safety functions. Since these systems in some advanced reactor design could provide an ultimate heat sink for the decay power, they serve a critical safety function. Given these systems reliance on passive methods, they may present novel security risk and unique vulnerabilities to radiological sabotage by insider threats and external adversarial attacks. Historically, evaluation of acts of indirect sabotage focused on primary threats to active system disruption or seizure, while considerations for passive systems (if present), were secondary. Thus, at the current time there is limited existing literature on the threats unique to passive systems. This paper presents a status and summary of an on-going project tasked with identifying the envelope of possible security threats to passive decay heat removal systems in advanced reactors. The project will determine which threats are most credible and realistic, assess these threats for their potential consequences on reactor safety, and establish recommendations to addressing the identified security concerns. Included in this paper is a narrative of the approach and methodologies to support threat determinations by reactor developers and other stakeholders. Results and findings by the project will be documented separately in a full report once the overall project is completed later this year, and issued to allow broad dissemination of the knowledge gained.

# A Path Toward Leveraging the Benefits of Safety, Security, and (International) Safeguards (3S) for Advanced & Small Modular Reactors(A/SMRs): Summary of the Institute of Nuclear Materials Management's Workshop on Advanced Reactor 3S


**Speaker: A. Williams**

Primary Author: Adam Williams [1]

Co-Authors: Tina Hernandez [2]; Kimberly Lawrence [2]; Mark Schanfein [3]

*[1] Sandia National Laboratories; [2] Institute of Nuclear Materials Management; [3] Idaho National Laboratory*


**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 10: Safety, Security and Safeguards Interfaces related to SMRs (C.10)

**INDICO Abstract ID: 215**


**Abstract**

Efforts to improve knowledge and application of interfaces between safety, security, and (international) safeguards—the so-called 3S—are important for advanced and small modular reactors (A/SMR). Having been addressed across technical meetings and professional conferences, the nuclear materials management professional community is seeking to leverage the anticipated benefits of 3S. To continue this discussion, in February 2024 the Institute for Nuclear Materials Management (INMM) convened the Advanced Reactor 3S workshop in Albuquerque, New Mexico. The workshop welcomed over 70 safety, security, and safeguards professionals from government, academia, and industry. Participants heard from over 20 expert speakers, as well as discussed potential 3S engineered solutions and "by-design" concepts to address interfaces. The two-day workshop brought together the experience of the INMM community to describe the current state-of-the-art—and investigate potential future solution—of 3S for A/SMRs. Workshop participants also provided insights into how effectively the INMM supports current 3S efforts, where 3S gaps, challenges, and needs exist, and recommendations on what INMM should do to support future 3S efforts. This paper synthesizes the 3S-related thoughts, concerns, key needs, and opportunities identified by the INMM community—

and offers potential pathways for A/SMRs to leverage the benefits of 3S interfaces. (SAND2024-02314A. SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525)

# Consideration of a Regulatory Framework for Safeguards in SMRs


**Speaker: S. Jeong**

Primary Authors: Seung Ho Ahn [1]; Chul Heo [2]; Seungho Jeong [2]; Seungmin Lee (kinac) [3]; Hosik Yoo [4]

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**Presentation Type: Poster**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 10: Safety, Security and Safeguards Interfaces related to SMRs (C.10)

**INDICO Abstract ID: 217**


**Abstract**

This study proposes a legal framework to integrate Safeguards by Design (SBD) principles from the design phase of Small Modular Reactors (SMRs), addressing the gap in current practices where safeguards are not considered early in the design and construction phases. The International Atomic Energy Agency (IAEA) encourages early cooperation among designers, operators, regulators, and itself to include detailed nuclear facility information from the beginning of the design phase. However, the existing process only mandates the submission of a preliminary Design Information Questionnaire (DIQ) seven months before construction, with a final DIQ submitted seven months before nuclear material arrival, missing early SBD adoption. The current legal foundation and licensing process, based on the Nuclear Safety Act, outlines construction and operation permit requirements but lacks integration of safeguards in the early stages. The study suggests amending the Nuclear Safety Act to include safeguards-related documentation in the licensing process, thereby facilitating SBD implementation. This includes expanding the Material Accounting Regulation for Nuclear Facilities (MARN) content to support SBD practices effectively. Additionally, utilizing subsidiary documents and the Regulation on the Report of International Strategic Materials (RISM) could enforce SBD principles by requiring the submission of design information at each construction stage. This approach requires proactive collaboration from licensees and a regulatory framework that includes specific penalties for non-compliance with design change disclosures. The study concludes that incorporating safeguards into the

licensing process through legislative amendments or by leveraging existing regulations could ensure SBD implementation from the initial design phase, emphasizing the need for close collaboration among all stakeholders to overcome current challenges in safeguard integration.

# Safety and Security of SMRs in marine applications and the Applicability of IAEA’s Safety Standards


**Speaker: W.s. Edwards**

Primary Author: Scott Edwards [1]

Co-Authors: Ioannis Kourasis [1]; Mamdouh El-shanawany [1]

*[1] Core Power*


**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 10: Safety, Security and Safeguards Interfaces related to SMRs (C.10)

**INDICO Abstract ID: 234**


**Abstract**

Nuclear reactors have a longstanding history of safe operation at sea, with approximately 12,000 reactor years of experience, underscoring their exceptionally high safety standards. This track record suggests that Floating Nuclear Power Plants (FNPPs) are capable of conforming to current international safety and environmental codes and requirements. Nonetheless, the unique challenges and site-specific risks posed by the marine environment, such as sea state conditions and the possibility of sinking or capsizing, necessitate careful consideration and analysis. The paper examines the applicability of IAEA’s Safety Assessment, Design and Security Requirements to Floating Reactors. The IAEA Safety and Security Standards, which represent international consensus on best international practices to achieve a high level of safety and security, will be used in assessing the safety and security of SMR designs for FNPPs.

# Achieving resilience through the preservation of functions - safety and security working together

**Speakers: M. St. John-green; M. Hewes [1]**

Primary Author: Michael Stjohn-green [2]

Co-Author: Mitchell Hewes [3]

*[1] TBC; [2] Mr; [3] IAEA*

**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 10: Safety, Security and Safeguards Interfaces related to SMRs (C.10)

**INDICO Abstract ID: 238**

**Abstract**

Advanced nuclear reactors, including Small Modular Reactors, promise enhanced safety and efficiency by harnessing complex digital technologies. However, these innovations also introduce risk management challenges regarding the computer security vulnerability of complex digital components to malicious action, faults and failure . Current nuclear industry approaches to safety and security operate with system-centric views, focusing on individual system robustness and redundancy. This approach overlooks functional interdependencies, resulting in a less efficient and resilient approach and potentially causing gaps in understanding and addressing threats and vulnerabilities. This paper advocates a paradigm shift towards unified risk management where safety, security, and operational integrity are complementary aspects of achieving resilience through the preservation of functions. Although applying such a model poses analytical and complexity challenges, it provides a path towards more resilient nuclear infrastructure. Recognising that safety and security fundamentally aim to uphold functional integrity facilitates collaboration between these domains. With the development of advanced nuclear reactors, the industry has a rare opportunity to develop new tools, techniques and working methods that foster cross-domain partnerships from the design phase onward. Ultimately, this integrated perspective on technological and organisational risk management will enable nuclear designers, regulators and operators to leverage the benefits of new and complex digital systems while ensuring robust safety and security.

# THE MEANING OF RISK FOR SAFETY, SECURITY, AND SAFEGUARDS IN THE DESIGN OF ADVANCED NUCLEAR REACTORS

**Speaker: D. Kovacic**

Primary Author: Donald Kovacic [1]

Co-Authors: Giacomo G.m. Cojazzi [2]; Guido Renda [3]

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**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 10: Safety, Security and Safeguards Interfaces related to SMRs (C.10)

**INDICO Abstract ID: 248**

**Abstract**

What is the meaning of risk as it applies to the design of advanced reactors in the disciplines of safety, security, and safeguards? How can we find common terminology for the concept of risk and how can we find synergies between these disciplines? These are important questions that should be explored in order that they may be applied in an integrated manner for the most effective and efficient design approaches. Eliminating or minimizing risks is a key design driver that motivates and informs the development of nuclear reactors. For safety, risk is well understood and applied in Probabilistic Risk Assessments. For security, the risk-based concepts of vulnerability assessments and vital areas are all considered in designing security systems. For safeguards, the concept of risk is not formally defined, as it relates to the design and operation of nuclear reactors. International nuclear safeguards seeks to reduce the risk of proliferation in the nuclear fuel cycle and as such the concept of risk does exist. Therefore, the current understanding of the "3S' approach, which seeks to find the synergies and conflicts between safety, security, and safeguards requires a thorough understanding of the role that the reduction of risk plays in all three disciplines. The intersection of risk for safety and security is now being developed as there is a strong correlation between reactor design and operations and their vulnerability to sabotage. The intersection of risk for security and safeguards has to date chiefly been focused on the nuclear material control

and accounting systems, which are relied on by both the operator (State) and the IAEA. This paper explores the concept of risk in each of the three disciplines, how they interact, potential conflicts and synergies, how these might be addressed and leveraged, and a notional framework for how this could be achieved.

# Safety, Security, and Safeguards (3S) Interface Identification and Characterisation in Generation IV Advanced Modular Reactors: A Generation IV International Forum Case Study

**Speaker: L. Ammirabile [1]**

Primary Authors: Luca Ammirabile [2]; Lap-yan Cheng [3]; Christopher Chwasz [4]; Benjamin Cipiti [5]; Giacomo G.m. Cojazzi [6]; Bryan Van Der Ende [7]; David Hummel [7]; Guido Renda [2]; Ryan Stewart [4]

*[1] TBC; [2] European Commission Joint Research Centre; [3] Brookhaven National Laboratory; [4] Idaho National Laboratory; [5] Sandia National Laboratories; [6] Retired; [7] Canadian Nuclear Laboratories*

**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 10: Safety, Security and Safeguards Interfaces related to SMRs (C.10)

**INDICO Abstract ID: 288**

**Abstract**

The Generation IV International Forum (GIF) is a co-operative international endeavour that was set up to facilitate the research and development (R&D) needed to establish the feasibility and performance of the next generation (Gen-IV) nuclear energy systems, establishing their performance goals and exploring technical feasibilities and designs, with the objective of making them available for industrial deployment by 2030s. Gen-IV reactor technologies will have to excel in four main areas: safety, economics, sustainability, proliferation resistance and physical protection. With the development of Gen-IV advanced modular reactor (AMR) designs, the GIF Proliferation Resistance and Physical Protection Working Group (PRPPWG), the GIF Risk and Safety Working Group (RSWG) and the GIF Very High Temperature Reactor System Steering Committee (VHTR SSC) are performing a bottom-up 3S (safety, security, and safeguards) exercise on a notional pebble-bed VHTR modular reactor. The objective of the exercise is to identify and characterize 2S and 3S interfaces on the reference system, and to abstract some technology neutral guidelines for 2S/3S interfaces identification and characterization. This paper will summarize the progress and experience emerging from this activity, together with some high-level findings and considerations.

# Safeguards by Design process of LDR-50 concept with consideration of safety and security

**Speaker: T. Honkamaa**

Primary Author: Tapani Honkamaa [1]

Co-Authors: Paula Karhu [1]; Olli Okko [1]; Ville Peri [1]; Marko Hänäläinen [1]; Jaakko Leppänen [2]

*[1] STUK; [2] VTT*

**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 10: Safety, Security and Safeguards Interfaces related to SMRs (C.10)

**INDICO Abstract ID: 354**

**Abstract**

Finnish LDR-50 is an SMR concept designed for district heating production. This paper examines the important integration of Safeguards by Design (SBD) principles within the development and deployment of LDR-50 design to ensure effective and cost-efficient implementation of nuclear safeguards. SBD process and relevant considerations related to 3S interfaces will be discussed. The concept of SBD involves integrating safeguards considerations into the design phase of nuclear facilities. While traditional large-scale nuclear reactors have well-established safeguards concepts, the unique characteristics of SMRs necessitate tailored approaches to address safeguards challenges effectively. A specific challenge is cost-efficiency from the perspective of both the IAEA safeguards and the nuclear operator. Key topics to be discussed in the paper include: • Design Integration: Examining strategies for seamlessly integrating safeguards measures into the security and safety processes of SMRs, considering operational flexibility. • Technological Solutions: Assessing the development of advanced technologies, such as remote operation and monitoring, to assist in achieving the objectives of SBD. Additionally, the reactor and its fuel handling processes should be designed with safeguards in mind, to avoid costly problems during construction, commissioning, and operation phases. • Regulatory Frameworks: Analyzing active role of regulatory body in Finland (STUK) in promoting SBD for LDR-50 design and developing new regulatory framework aiming at efficient implementation of safeguards in SMRs together with safety and security. • International Collaboration: Highlighting the importance of

international cooperation and knowledge-sharing initiatives to facilitate the adoption of SBD practices.

# Applying 3S Lessons: Using Safety Concepts to Develop "Risk-Informed Safeguards" for Small Modular Reactors

**Speaker: C. Faucett**

Primary Author: Chris Faucett [1]

Co-Author: Adam Williams [1]

*[1] Sandia National Laboratories*

**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 10: Safety, Security and Safeguards Interfaces related to SMRs (C.10)

**INDICO Abstract ID: 365**

**Abstract**

A challenge in integrating security/safety/safeguards (3S) is how to communicate risks given the vastly different technical competencies among subject matter experts in each domain. Similar to conceptual parallels between safety and security (i.e., similar perception of consequences and owner/operator responsibilities), safeguards could benefit by leveraging alternative models to better communicate risk. More specifically, developing clearer descriptions of the potential for incredible high consequence events related to safeguards (including the importance of safeguards-by-design) could help support the responsible development of advanced/small modular reactors. To this end, this paper introduces an alternate perspective that borrows concepts from nuclear safety to better communicate risks in the safeguards domains. Recently, the safety concept of risk significance (defined as a level of risk exceeding a predetermined threshold) and organizational gradients was used to develop a conceptual “insider risk significance” framework for multi-insider threats. Using key similarities between State-level diversion and subnational theft, this paper conceptualizes a similar “safeguards risk significance” framework for better characterizing safeguards risks for SMR deployment. While still conceptual, a "risk-significant" model could help inform and optimize efforts to improve safeguards efforts aligned with future needs of A/SMR deployment. SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525

# Implementation of 3S by INPRO

**Speaker: C. Scherer**

Primary Author: Nilormi Das [1]

Co-Author: Carolynn Scherer [2]

*[1] IAEA-INPRO; [2] IAEA - INPRO*

**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 10: Safety, Security and Safeguards Interfaces related to SMRs (C.10)

**INDICO Abstract ID: 386**

**Abstract**

The International Atomic Energy Agency (IAEA) integrates activities in safety, security, and safeguards (3S) and promotes the concept of 3S by design. The IAEA objectifies to harmonize the 3S interfaces in an integrated manner to avoid compromise of any one realm over the others. The International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO), a key programme of the IAEA, assesses innovative reactors and fuel cycles for sustainability. In alliance with 3S, INPRO incorporates 3S concept through three of the six assessment areas: safety, security through the infrastructure assessment area, and safeguards through the proliferation resistance assessment area. In the past several years INPRO initiated collaborative projects to assess the sustainability of (small modular reactors) SMRs. The INPRO methodology is being applied for successful and sustainable development and deployment of SMRs meeting the global energy needs. The INPRO assessment identifies areas where criteria are not fulfilled, and designers need to redesign to satisfy that the SMR is sustainable. Often with innovative systems the assessment can identify gaps that need to be addressed through research and development (R&D). INPRO activities supports the IAEA's 3s in a holistic manner for sustainable deployment of SMRs.

# Reactor Designer Lessons Learned on the Approach to Safeguards by Design for Small Modular Reactors; Opportunities and Challenges

**Speaker: J. Bredenkamp**

Primary Authors: Jo Anna Bredenkamp [1]; Isaac Caretti [1]; Nancy Closky [1]; Emily Hunt [1]; Jessica Levy [1]

*[1] Westinghouse*

**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 10: Safety, Security and Safeguards Interfaces related to SMRs (C.10)

**INDICO Abstract ID: 412**

**Abstract**

The practical implementation of safeguards by design (SBD) in first-of-a-kind small modular reactors presents a challenge to reactor designers because regulations and policies are silent on safeguards measures, or if at all, specified during deployment rather than during the design phase. Detailed requirements for domestic and IAEA safeguards systems depend upon site, design, and country specific factors, however, there is a need to standardize the applicable safeguards systems for all cases within the standard design to reduce schedule, clearly define scope, and minimize budget risk. SBD implementation for SMRs is especially challenging because existing tools and methodologies applied to previous reactor designs do not meet the needs of new reactor designs due to various design enhancements including smaller overall site footprints and new nuclear fuel types. The application of safeguards technology and processes provides an opportunity to implement the SBD as a more proactive stance during the overall plant design and layout. The detailed requirements for safeguards system depend upon site, the reactor design, and country-specific factors; however, there is a desire in the industry to make a standard physical safeguards system applicable for standard reactor designs. Despite support for industry incorporating SBD, policies, procedures, State-specific laws, and regulations do not provide a clear or consistent pathway for vendor and designer interactions for early safeguards implementation. There are many hurdles regarding direct communication and partnership with the IAEA and their delegates in the deployment of safeguards, including

requirements to work through owners, countries, and regulators. By proactively incorporating the reactor designer and vendors into this process early, SBD can streamline the implementation of nuclear safeguards systems throughout design, construction, and operation, reducing the overall cost of safeguards programs. The challenges of timing and managing budget and schedule risk can only be addressed by inclusion of new partners in the implementation of safeguards and to achieve the objective of SBD of the new fleet of nuclear reactors.

# FRENCH LESSONS LEARNT REGARDING INTERFACES BETWEEN SECURITY AND SAFETY AND SAFEGUARDS, FOR SMRS


**Speaker: M. Koppe**

Primary Authors: Rã©gine Gaucher; Mélissa Koppe Regamoundjou; Thomas Languin [1]

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**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 10: Safety, Security and Safeguards Interfaces related to SMRs (C.10)

**INDICO Abstract ID: 431**

## Abstract


The French nuclear regulatory framework comprises three distinct areas: Safety, Security and Safeguards, each of which is overseen by different regulatory bodies. The coordination among these authorities is crucial, with regular meetings held to facilitate information exchange. This paper will present the current experience with this coordination between the Nuclear Security Authority and the other two authorities. Among other things, it will address the following issues: - Major safety enhancements incorporated in the design of these SMRs may not be relevant to nuclear security; - As a consequence, synergies between safety and security for SMRs could have limited potential compared to normal reactors, as malicious attacks could have the potential to destroy a more important part of the reactor at once; - The cost of nuclear security could be proportionately higher and perhaps similar to the cost of safety, whereas for normal reactors it is often significantly lower.

## Track 11: Security of SMR: Physical Protection and Computer Security (C.11)

# Transitioning Regulatory Oversight: Moving from Prescriptive to Performance-Based Approach for Addressing Security Challenges in Indian SMRs


**Speaker: K. Ghoshal**

Primary Authors: Kaushik Ghoshal (department Of Atomic Energy; Government Of India; Csm Marg, Mumbai 400001; India); Anek Kumar [1]; Garima Sharma (department Of Atomic Energy; India)

*[1] Department of Atomic Energy, India*


**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 11: Security of SMR: Physical Protection and Computer Security (C.11)

**INDICO Abstract ID: 176**


**Abstract**

Abstracts: The deployment of small modular reactors (SMRs) holds significant promise for India's energy security and sustainability goals. However, the unique security challenges due to their modularity, potential deployment in urban locations, and evolving design characteristics pose unique security challenges. The existing prescriptive based regulatory requirements (nuclear security), tailored for conventional reactors, might not adequately address these SMR-specific security concerns. Therefore, it is imperative to conduct a thorough evaluation of existing nuclear security requirements to ensure they effectively address these concerns and facilitate compliance. This abstract presents a study aimed at evaluating the adequacy of India's nuclear security requirements in addressing security challenges associated with SMR deployment and proposes recommendations for enhancing regulatory oversight and compliance. The study employs a mixed-methods approach, combining qualitative analysis of nuclear security requirements documents and guidelines with stakeholder's expectation and expert consultations. The analysis focuses on key aspects of India's regulatory requirements, including licensing requirements, security standards, emergency preparedness, and

regulatory enforcement mechanisms. Additionally, international best practices are reviewed to benchmark India's regulatory approach against global standards.

# GENERAL APPROACHES TO PHYSICAL PROTECTION OF SMALL MODULAR REACTORS

**Speaker: S. Marogulov**

Primary Authors: Ruslan Baychurin [1]; Sergei Marogulov [1]

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**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 11: Security of SMR: Physical Protection and Computer Security (C.11)

**INDICO Abstract ID: 187**

**Abstract**

The responsibility for establishing its own physical protection regime of nuclear material and nuclear facilities rests entirely with the State. As with other nuclear facilities, any type of small modular reactors requires implementation of physical protection measures. The establishment of a physical protection system for small modular reactors should be based on the fundamental principles and categorization of nuclear material defined by the Convention on the Physical Protection of Nuclear Material and Nuclear Facilities. Based on the category of nuclear material used, the physical protection system of a specific atomic energy facility is being established. New technologies of small modular reactors have a number of differences, including their compactness, mobility and the ability to be located in remote regions. The compactification of nuclear technologies implemented in small modular reactors should not mean an automatic and proportional reduction in the amount of funds and resources required to ensure their physical protection (such as the installation of engineered features, hiring and training of physical protection personnel, the cost of maintaining an effective physical protection system). General approaches to and possible challenges for maintaining physical protection of small modular reactors will be set forth in the paper.

# Development of a Robust Framework for Security Assessment of Safety-Informed Siting Decisions under Uncertainty

**Speaker: A. Adeniyi**

Primary Author: Abiodun Adeniyi [1]

Co-Author: Olufemi Omitaomu [1]

*[1] Oak Ridge National Laboratory*

**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 11: Security of SMR: Physical Protection and Computer Security (C.11)

**INDICO Abstract ID: 200**

## Abstract

**Development of a Robust Framework for Security Assessment of Safety-Informed Siting Decisions under Uncertainty** Abiodun Adeniyi a,b,*, Olufemi Omitaomu, PhD c a Nuclear Energy and Fuel Cycle Division, Oak Ridge National Laboratory, Oak Ridge b Energy Science and Engineering, Bredesen Center, University of Tennessee, Knoxville c Computational Sciences and Engineering Oak Ridge National Laboratory, Oak Ridge *Corresponding Author: Abiodun Adeniyi, adeniyiai@ornl.gov **ABSTRACT** *The assessment of security vulnerabilities during the initial phase of locating a nuclear reactor facility involves a process aimed at recognizing specific site attributes that could expose the site to potential security risks. Early identification of such features is crucial as they might increase the site's susceptibility to malicious attacks. Any security incident or event could harm life, the environment, or property. Additionally, certain site characteristics such as its location and the shortest route from the responders can impact response to emergencies at the site. Features such as slope and extreme weather events could influence the efficacy of implemented measures in reducing security risks at the selected site. If an issue with a site's potential risk factor is identified early, a more cost-efficient plan can be incorporated into the overall site design. However, once a site is chosen and construction commences, any discovery of natural or artificial features that render the site vulnerable to security threats could lead to construction delays and additional expenses in designing and implementing necessary security measures. This paper aims to emphasize the deficiencies in the evaluation framework used to assess security risks at potential nuclear reactor sites during the site selection phase. Our research underscores the necessity for establishing a robust framework to assess security vulnerabilities in nuclear facility siting, aiming to address these gaps effectively.* Keywords: site security, vulnerability assessment, siting, nuclear threat, nuclear security, threat mitigation, OR-SAGE

# SECURITY BY DESIGN: UNDERSTANDING HOW TO APPLY IT TO SMR

**Speaker: A. Malabirade**

Primary Authors: Mélissa Koppe Regamoundjou; Thomas Languin [1]

*[1] MINISTRY OF ENVIRONMENT, ENERGY AND THE SEA FRANCE*

**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 11: Security of SMR: Physical Protection and Computer Security (C.11)

**INDICO Abstract ID: 202**

**Abstract**

Security by design is of paramount importance for all nuclear facilities, but even more so for SMRs. In fact, preliminary studies show that nuclear security could be one of the main operating costs of SMRs. Security by design offers a unique opportunity to design reactors that are more cost-effective and competitive. This paper will explain, based on the French experience, why nuclear security should be better taken into account from the beginning. While it is not possible to share confidential information in an international conference, the historical example of the Opéra Garnier, one of the most famous buildings in Paris, will be used to illustrate the concept of security by design. Who remembers today that security was one of the concerns of this building? In fact, its construction was decided after a bomb attack against Napoleon by Italian terrorists in front of the Paris Opera. The principles applied to the Opéra Garnier are still relevant for SMRs, including a global approach to the protection of the facility and the transportation of nuclear materials, protection against stand-off attacks, and optimization of access to reduce the insider threat.

# FRENCH SMRS: LESSONS LEARNT FROM TWO YEARS OF REGULATORY SUPPORT FOR SMR PROJECTS

**Speaker: R. Gaucher**

Primary Authors: Mélissa Koppe Regamoundjou; Thomas Languin [1]

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**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 11: Security of SMR: Physical Protection and Computer Security (C.11)

**INDICO Abstract ID: 203**

**Abstract**

Following the launch of President Macron's 'France 2030' plan in February 2020, a dozen SMR designers have contacted the Département de la sécurité nucléaire (DSN), the French nuclear security authority, to seek regulatory support for implementing security by design. SMR projects pose challenges for the DSN as the designers lack practical knowledge of nuclear security and do not have access to classified information such as the DBT. These projects are planned to be installed in great numbers in locations where there are no nuclear facilities today and near populated areas. This represents a complete paradigm shift from the current French nuclear location. The DSN had to adapt and create a new process to support SMR designers. This paper will present the lessons learned related to the challenges faced and how the DSN addressed them, including the optimization of human resources, coordination with other competent authorities, drafting a guidance on security by design for SMRs and a step-by-step approach for technical dialogue on protected information, particularly for DBT.

# SECURING SMALL MODULAR REACTORS IN URBAN ENVIRONMENT

**Speaker: A. Evans**

Primary Author: Collin Evans

**Presentation Type: Poster**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 11: Security of SMR: Physical Protection and Computer Security (C.11)

**INDICO Abstract ID: 216**

**Abstract**

Current small modular reactor (SMR) deployment use cases consider both rural and urban deployments depending on the operational need and in-country needs for clean and reliable sources of energy. Many studies have been conducted analyzing security in more rural and remote deployment locations, but this study looks at the physical security implications of an SMR placed in an urban environment and its uses for electricity production, district heating, and process heating. SMRs used for electricity production, district heating, and process heating may be key sources of both energy infrastructure and commercial infrastructure within a city. Therefore, operators may consider further security applications to protect an SMR plant from physical attacks against both radiological sabotage and sabotage acts that could result in the SMR facility going down for a significant amount of time. These long-term shutdowns of an SMR facility may have a serious impact on the overall energy production or commercial production in a country. In this study, the team will design and analyze a physical security system for securing an urban SMR facility against acts of radiological sabotage and sabotage acts that could disrupt the facility's long-term operation. Additionally, this work will analyze the nuanced security issues related to siting an SMR near an urban environment versus in a rural environment. Finally, this work will include recommendations for physical security for urban SMR facilities used for energy production, district heating, and process heating.

# Introduction of a cyberattack detection framework for safety systems of NPPs


**Speaker: T. Kim**

Primary Author: Taejin Kim [1]

Co-Authors: Inhye Hahm [1]; Young-jun Lee [1]

*[1] Korea Atomic Energy Research Institute*


**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 11: Security of SMR: Physical Protection and Computer Security (C.11)

**INDICO Abstract ID: 226**


**Abstract**

As cyberattack becomes more complex and intelligent, an air-gapped computer or network of nuclear power plants cannot guarantee 100% safety from cyberattacks. For the Iranian nuclear facility in 2010, a malicious computer worm broke into the nuclear program and disabled the key part although the target was located in the air-gapped facility. In most small modular reactors(SMRs), the instrumentation and control(I&C) systems are digitalized. They are designed to comply with codes and standards of cybersecurity, but there are few detection systems for cyberattacks. Especially for safety systems, no direct cyberattack detection system is applied because there is a big concern about impacts of safety functions as new security system is introduced in the I&C architecture. Thus, this study suggests a framework to detect cyberattacks in safety systems without affecting direct safety functions based on the study of APR1400.

# Research on Gaps in Domestic Regulatory Documentation Based on Security Regulatory Cases of SMRs in Other Countries

**Speaker: S. Lee**

Primary Author: Subong Lee [1]

Co-Authors: Kookheui Kwon [1]; Donghyuk Lim [1]; Sundo Choi [1]

*[1] Korea Institute of Nuclear Nonproliferation And Control*

**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 11: Security of SMR: Physical Protection and Computer Security (C.11)

**INDICO Abstract ID: 239**

**Abstract**

Small Modular Reactors (SMRs) are defined as reactors of small to medium size,producing up to 300 MW(e) (small-sized or small modular) or 300 to 700 MW(e)(medium-sized). More than 80 SMRs are under development worldwide, such as the U.S., Canada, Russia, the U.K., China, and others. Under SMR development, nuclear regulatory bodies in the U.S., U.K., and Canada have established close cooperation with SMR developers and are proceeding with the review process. As an illustration, the U.S. Nuclear Regulatory Commission (NRC) has initiated a rulemaking process referred to as Title 10 of the Code of Federal Regulations (CFR) Part 53 and Part 73.110, aimed at suggesting a new regulatory framework for advanced reactors along with accompanying regulatory guidance. During the pre-application reviews, the Design-Specific Review Standard (DSRS) for NuScale Design has been developed to provide guidance to the NRC technical staff for reviews not covered by the existing NRC standard review plan (SRP). Currently, the Republic of Korea (ROK) is in the process of developing an innovative Small Modular Reactor (i-SMR) capable of producing up to 170 MW(e). The major milestones include finalizing the basic design and standard design by 2026 and obtaining regulatory certification by 2028. Conducting a gap analysis between domestic regulatory documents and international SMR security-related regulatory frameworks is essential to prepare for the development of i-SMR. In this study, firstly, a review of security regulatory documents applicable to i-SMR in the ROK is necessary. Secondly, an analysis of regulatory documents developed and applied for SMR security abroad is

required. Then, this study derives a development strategy for security regulatory documents through gap analysis between international and ROK security regulatory documents.

# cybersecurity matter for remote access of SMR

**Speaker: S. Boulley, A. Benoit Rosario [1]**

Primary Author: Olivier Dhenin [2]

Co-Authors: Abel Benoit Rosario [3]; Olivier Fichot [2]

*[1] TBC; [2] IRSN; [3] Ministry in charge of nuclear security*

**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 11: Security of SMR: Physical Protection and Computer Security (C.11)

**INDICO Abstract ID: 249**

**Abstract**

Remote operation is a crucial aspect of the business model for some Small Modular Reactor (SMR) operators, encompassing Physical Protection Systems (PPS) and I&C systems. However, the reliance on digital technologies raises viability concerns related to the growing potential for cyber attacks. This paper presents a study on cyber security issues of remote communication and identifies technical vulnerabilities related to potential unmanned teleoperated SMR plants. It proposes a new implementation that complies with the defense in depth principle highlighted in NSS 17 that relies on nested VPN tunnels for both PPS and I&C operation. This approach is compared with other possible implementations, addressing their advantages and drawbacks. The study also examines some of the implementable solutions in terms of encryption algorithms to consider the whole lifecycle of SMR operations. The document proposes generic recommendations for telecommunication hardware to take account of diversity and segmentation of usage principles. This study also analyses the French regulatory framework in order to identify the potential adaptations required for the development of such systems.

# Incorporating International Considerations into Systems Engineering and Regulatory Lifecycle-Based Framework for Security-by-Design

**Speaker: A. Williams**

Primary Author: Adam Williams [1]

Co-Authors: Alan Evans; Katherine Holt [2]; Steven Horowitz [1]

*[1] Sandia National Laboratories; [2] National Nuclear Security Administration*

**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 11: Security of SMR: Physical Protection and Computer Security (C.11)

**INDICO Abstract ID: 253**

**Abstract**

The popularity of advanced and small modular reactors (A/SMR) is driving "security-by-design" (SeBD) efforts. Current approaches range from applying traditional protection strategies "early in the design lifecycle" to seeking "intrinsic security…as an integral part of the organization" to making "security…[a] part of the facility lifestyle." Yet, international A/SMR considerations highlight an opportunity to recharacterize SeBD options. In response, the U.S. National Nuclear Security Administration's (NNSA) Office of International Nuclear Security (INS) and Sandia National Laboratories have developed a systems engineering and regulatory lifecycle-based framework for SeBD. This framework has two goals. First, it identifies opportunities that exist for achieving security goals at each A/SMR lifecycle stage. Second, it categorizes those SeBD options related to which stakeholder (including the designer or utility) might have primary responsibility. Consider, for example, the International Atomic Energy Agency's safety guide SSG-20. If SSG-20 is considered part of an engineering and lifecycle model of A/SMR development, then this SeBD approach should identify opportunities to claim credit for security performance that align with safety and operations-relevant A/SMR decisions described in SSG-20. This paper will use demonstration cases to describe this framework, as well as offer lessons insights for incorporating SeBD in—and improving security for—A/SMRs. (SAND2024-02355A. SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525)

# Developing Regulatory Frameworks for A/SMRs: Security by Design and Other Regulatory Considerations

**Speaker: P. Eftekhari**

Primary Author: Pegah Eftekhari

Co-Author: Madalina Man (pacific Northwest National Laboratory) [1]

*[1] Pacific Northwest National Laboratory (PNNL)*

**Presentation Type: Poster**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 11: Security of SMR: Physical Protection and Computer Security (C.11)

**INDICO Abstract ID: 263**

**Abstract**

The diversity of advanced reactor and small modular reactor (A/SMR) designs, combined with various modes of deployment and specific circumstances with respect to a country's threat assessment and design basis threat (DBT) or representative threat statement (RTS), raise new regulatory challenges and the need to adapt existing legislative and regulatory frameworks for nuclear security to account for the particularities of future A/SMR deployments. Establishing robust Security by Design (SeBD) regulatory requirements is essential for regulators and future operators to effectively address some of the potential security challenges posed by the future deployment and operation of A/SMRs. This paper discusses some of the regulatory challenges pertaining to the security of A/SMRs and embarks on a legal analysis of laws and regulations that illustrate how some of these challenges may be addressed. Based on open-source information, this paper analyzes legislative and regulatory provisions that could be leveraged to support SeBD and other security considerations for A/SMRs and identifies related references in IAEA nuclear security series publications. Based on the results of this analysis, the paper discusses several regulatory provisions that embarking and expanding countries may consider adding or enhancing in their frameworks as they further develop or adapt existing regulatory documents to ensure the secure deployment of future A/SMRs. Among other topics, the analysis will focus on SeBD requirements and their consideration in the licensing process. (Released under PNNL-SA-195386)

# Study on Standard Design Review Areas for Security-by-Design of SMR

**Speaker: K. Kwon [1]**

Primary Author: Kookheui Kwon [2]

Co-Authors: Donghyuk Lim [3]; Sundo Choi [3]; Subong Lee

*[1] TBC; [2] Korea Institute of Nuclear Nonproliferation And Control; [3] KINAC*

**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 11: Security of SMR: Physical Protection and Computer Security (C.11)

**INDICO Abstract ID: 270**

**Abstract**

Nuclear security measures are required for nuclear power plants to prevent radiological sabotage and unauthorized removal of nuclear materials. For this purpose, prevention, detection, delay, and response security measures for physical protection and cyber security are performed, and related systems are installed. As these security measures and systems are related to the plant design and can affect plant safety and operations, the IAEA Nuclear Security Series and Safety Standards require integrated consideration from the plant design stage, as follows; - IAEA Nuclear Security Series No. 13 (INFCIRC/225/Rev. 5) (Fundamental Principle E) For a new nuclear facility, the site selection and design should take physical protection into account as early as possible and also address the interface between physical protection, safety and NMAC to avoid any conflicts and to ensure that all three elements support each other. -IAEA Safety Standards No. SSR-2/1 (Rev.1) (Requirement 8) Safety measures, nuclear security measures and NMAC for a nuclear power plant shall be designed and implemented in an integrated manner so that they do not compromise one another. In particular, compared to large nuclear power plants, SMRs have many novel aspects and limitations, which may affect not only safety but also security. Therefore, it is essential to design SMR holistically, by integrating physical security and cyber security, into an effective system. As cyber threats evolve rapidly and the use of programmable digital systems increases, integrated design of physical and cyber security is important to achieve robustness of the SMR's security system. For these reasons, this paper will analyze physical protection and cyber security areas that need to be reviewed from a security perspective for various

standard designs of SMRs and cover key references for review, interface with other technical areas, documents required from vendors, and review criteria to consider.

# Physical Protection Modeling and Simulation Tools to Optimize Security for New Reactors


**Speaker: R. Iyengar**

Primary Author: Albert Tardiff [1]

*[1] US Nuclear Regulatory Commission*



**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 11: Security of SMR: Physical Protection and Computer Security (C.11)

**INDICO Abstract ID: 294**



**Abstract**

In 2008, the U.S. Nuclear Regulatory Commission (NRC) issued a policy statement that stressed the importance of considering safety and security requirements together in the new reactor design process, so that security issues (e.g., newly identified threats of terrorist attacks) can be effectively resolved through facility design and engineered security features (Federal Register, Vol. 73, No. 199, page 60612, dated October 14, 2008). Incorporating physical security into the designs of new nuclear facilities can avoid future, costly retrofits. Numerous commercial- and government-developed physical protection modeling and simulation (M&S) tools exist to help new reactor designers and vendors design physical security elements into their new reactor facilities. Those physical protection M&S tools can perform one or more of several functions related to the design or evaluation of a physical protection program or protective strategy, including facility characterization, adversary pathway analyses, combat simulation, and physical security system effectiveness. The NRC is assessing the appropriate uses of physical protection M&S tools for designing, validating, and modifying physical protection programs and protective strategies associated with new reactors for two primary purposes. First, the NRC wants its security staff to be prepared to accurately review new reactor license applications, and conduct inspections at new reactor sites, that may rely on physical protection programs or elements that have been designed or modified using physical protection M&S tools. Second, the NRC intends to incorporate lessons that it learns from the assessment into the guidance for industry that it plans to issue within the next 2 years. A paper based on this abstract will describe the details of the approach that the NRC staff is utilizing to form policy for the regulatory oversight of physical protection M&S tools.

# NRC Regulatory Efforts for Cybersecurity of Small Modular Reactors

**Speaker: T. Rivera**

Primary Author: Tammie Rivera [1]

Co-Author: Ismael Garcia [1]

*[1] U.S. Nuclear Regulatory Commission*

**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 11: Security of SMR: Physical Protection and Computer Security (C.11)

**INDICO Abstract ID: 301**

**Abstract**

The U.S. Nuclear Regulatory Commission, supported by cybersecurity experts from the national laboratories, has proposed a technology-inclusive, performance-based, and risk-informed cybersecurity regulatory framework for advanced reactor operators including Small Modular Reactors (SMRs). This regulatory framework aims to provide a process that accounts for the differing risk levels within SMR technologies, while also providing reasonable assurance of adequate protection of public health and safety, promoting the common defense and security, and protecting the environment. A key outcome of the regulatory framework is to provide an approach that would allow for the development and implementation of a cybersecurity program to meet demands for protection against the unacceptable consequences from a cyber-attack. The paper will discuss and analyze some key assumptions and trends relevant to cybersecurity of SMRs. First, the NRC expects SMRs to have increased reliance on digital systems, emerging technologies, passive safety features, and other novel design features. Additionally, designers are planning novel use cases, such as remote and autonomous operations, which demand reassessment of the applicability of existing paradigms such as network isolation, common in the existing power reactor fleet. Finally, harmonization of international standards and approaches may support more sophisticated security concepts, including security by design, customized control catalogs, and more performance-based objectives.

# Machine Learning Solutions for Enhanced Security in Small Modular Reactors (SMRs): A Comprehensive Approach

**Speaker: G. Abdiyeva-aliyeva**

Primary Author: Gunay Abdiyeva-aliyeva [1]

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**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 11: Security of SMR: Physical Protection and Computer Security (C.11)

**INDICO Abstract ID: 322**

**Abstract**

In the realm of Small Modular Reactors (SMRs), ensuring robust security measures is imperative to safeguard against potential threats to both physical infrastructure and computer systems. This article presents a thorough investigation into machine learning (ML) solutions to fortify security measures within SMRs. It begins with a detailed analysis of the multifaceted security considerations, encompassing physical infrastructure and cyber systems, essential for the safe operation of SMRs. Having described the foundation of SMR, different ML algorithms are offered as a solution to strengthen the security measures. Namely, anomaly detection algorithms, such as Isolation Forest and tree-based classification algorithms, such as Random Forest, all tailored for real-time monitoring and early detection of potential security breaches. Clustering algorithms such as K-Means and DBSCAN are examined for their ability to identify and analyze patterns within security incident data, aiding in the development of targeted security protocols. By integrating these diverse ML solutions, this article contributes to the advancement of security measures in SMRs, offering valuable insights for practitioners and researchers involved in nuclear energy security and safety.

# Insider Threat Security Considerations for Advanced and Small Modular Reactors

**Speaker: R. Peel**

Primary Authors: Zenobia Homan [1]; Ross Peel [1]

*[1] King's College London*

**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 11: Security of SMR: Physical Protection and Computer Security (C.11)

**INDICO Abstract ID: 381**

**Abstract**

The wide range of nuclear power plant technologies currently in design globally have a range of unique characteristics that create novel security considerations compared to large conventional nuclear power plants. Some of these characteristics create insider threat considerations for nuclear security, where insiders are defined as individuals with legitimate access to nuclear facilities and materials who use this access to carry out sabotage or theft of nuclear material. These include a lack of mature security culture in developer organisations, serial plant manufacturing in a production line environment, plant siting in remote and isolated areas, minimised staff numbers, teleoperation of plants by offsite staff, the increased reliance on digital instrumentation and control systems, and the potential for greater involvement of foreign experts and third-party suppliers, especially on short-term bases for, e.g, refuelling and maintenance. The paper takes a technology agnostic approach to examine what these factors may mean for insider threat risks and suggests that plant designers should be identifying and minimising the opportunities of insiders to act throughout the engineering design process. Doing so is anticipated to lead to much more effective insider threat mitigation in deployed small and advanced reactors.

# Nuclear Industry Views on the Security of Small Modular Reactors

**Speaker: R. Peel**

Primary Authors: Ronan Cavellec [1]; Nathan Paterson [1]; Ross Peel [2]

*[1] World Nuclear Association; [2] King's College London*

**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 11: Security of SMR: Physical Protection and Computer Security (C.11)

**INDICO Abstract ID: 383**

**Abstract**

Small Modular Reactors (SMR) present a range of novel characteristics which have the potential to create security considerations. These characteristics can be categorised according to six areas: (1) Power Capacity and Modular Manufacture and Construction, (2) Reduced Capital and Operating Costs, (3) Increasing Automation and Remote Operations, (4) Advanced Reactors and Fuels, (5) Deployment and Siting Options, and (6) Developer Business Models and Marketing Approaches. Prior work in this field has identified a range of security considerations unique to novel advanced reactors and SMRs. In order to build upon this, during March and April 2024, the World Nuclear Association's 65-member Nuclear Security Working Group was surveyed to collect views on nuclear security considerations for SMR and other advanced nuclear power plant designs. The Working Group's members are distributed globally, with a wide range of experiences and expertise in nuclear security. The paper will present and discuss the results of this survey. A number of novel security considerations were identified by the Working Group members, and these will be explored, with potential mitigation approaches presented.

# A review on Security in Small Modular Reactors and Micro Nuclear Reactors

**Speaker: J.c. Garcia**

Primary Authors: Julia Garcia [1]; Elaine Aparecida Rodrigues [2]; Ricardo Vendramel [3]; Delvonei Alves De Andrade [4]

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**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 11: Security of SMR: Physical Protection and Computer Security (C.11)

**INDICO Abstract ID: 409**

**Abstract**

Small Modular Reactors (SMRs) constitute an option for generating electricity and processing heat from nuclear energy, with advantages over large-scale nuclear power plants such as flexibility in location, improved safety, and reduced construction time. SMRs can also be designed as microreactors, aiming at relatively low energy production for industrial facilities, remote off-grid locations, military installations, and areas recovering from natural disasters. Due to their reduced dimensions and the market trend towards their large-scale use, additional security and proliferation aspects need to be adequately evaluated. As physical security is a critical consideration for SMRs, due to the protection of reactors, people, and the environment against a variety of potential threats, the objective of this study is to analyze the existing literature, identifying patterns, gaps, and trends to provide insights into the challenges and strategies related to the physical security of these emerging technologies.

# Safeguards by Design and Advanced Reactors: Overcoming the Catch-22 to Implementation

**Speaker: N. Mayhew**

Primary Author: Noah Mayhew [1]

*[1] Vienna Center for Disarmament and Non-Proliferation*

**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 12: Safeguards for SMRs (C.12)

**INDICO Abstract ID: 10**

**Abstract**

Safeguards by design (SBD) is vital to ensuring “safeguardability” of novel, small modular, and other advanced nuclear reactors and facility types, as well as maintaining safeguards effectiveness and efficiency for such facilities. The IAEA encourages SBD among facility designers and vendors, but it is not a requirement the IAEA can enforce and instead the onus is on industry to deliver it. However, the practical application of SBD is poorly understood for specific facility types and many advanced reactor developers are new to safeguards and often unaware of safeguards requirements. The few designers that do engage the IAEA often seek an IAEA’s “seal of approval” to make designs more marketable, which the IAEA cannot give. However, the IAEA and national governments are often constrained in their ability to conduct outreach to reactor designers as this would be viewed as promoting one designer over another. This creates a scenario where the IAEA looks to Member States and industry, Member States look to industry and back to the IAEA, and industry often looks back to the IAEA, if at all. The paper will describe this “Catch-22” in SBD implementation, describe some practical implications of SBD, and suggest paths forward for effective implementation.

# Integration of Small Modular Reactors in the Swedish Nuclear Energy System: A Proliferation Resistance Study

**Speaker: C. Olaru**

Primary Author: Claudia Olaru [1]

Co-Authors: Erik Branger [1]; Sophie Grape [1]

*[1] Uppsala University*

**Presentation Type: Poster**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 12: Safeguards for SMRs (C.12)

**INDICO Abstract ID: 100**

**Abstract**

The International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) has developed a comprehensive methodology to assess the sustainability of nuclear energy systems in terms of environmental impact, safety, proliferation resistance, waste management, infrastructure, and economics. Within the framework of the newly-established competence centre in Sweden entitled Academic-industrial Nuclear technology Initiative to Achieve a sustainable energy future (ANItA), we apply this methodology to explore the potential extension of the Swedish nuclear power programme through the introduction of Small Modular Reactors (SMRs). The analysis takes into account several key factors, including reactor design, deployment units, location, and mode of operation. Our primary focus is to evaluate the proliferation resistance of the envisioned nuclear energy system from multiple perspectives. This includes the non-proliferation legal framework applicable in Sweden, available nuclear technology and materials, and implemented safeguards considerations in operating procedures and SMR designs. Furthermore, we deliberate whether SMRs can still be subject to safeguards approaches applied for large-scale reactors, and address challenges associated with their future safeguards verification. Lastly, we explore technical solutions and construct a set of recommended proliferation resistance measures aimed at supporting designers, vendors, operators, and regulators in their efforts to foster a sustainable and safe energy future.

# Westinghouse Electric Company: Decarbonization of the Electric Power Sector and the Challenges Facing Advanced Reactors to incorporate Safety, Security and Safeguards Measures

**Speaker: I. Ezelarab [1]**

Primary Author: Ibrahim Ezelarab [2]

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*[1] TBC; [2] Westinghouse Electric Company*

**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 12: Safeguards for SMRs (C.12)

**INDICO Abstract ID: 151**

**Abstract**

Reducing greenhouse emissions while expanding energy access for economic development is an energy sector challenge requiring electrical power generation without fossil fuels. The nuclear industry's contribution can be enormous if the cost of new nuclear plants can be minimized. However, novel technologies introduce inherent financial, technical, and licensing challenges. System developers must understand the safety, security and safeguards requirements, their interfaces, opportunities for integration, and implementation challenges. Westinghouse Electric Company (Westinghouse) is developing a corporate Safeguards by Design program for the eVinci™ Micro-Reactor, thus accepting risk into the reactor design process by addressing requirements and costs traditionally borne by the facility operator and State and based upon the facility location and final design. This fundamental change requires close and meaningful interaction between State, regional, and international safeguards stakeholders and industry. Shifting all, or part of this burden to the reactor designers, without the customer and State identified will result in increased development and production costs. While the economic costs and benefits of safeguards by design are still unknown, the promise of overall cost savings and increased market access at the deployment phase has tipped the incentives toward a safeguards by design program.

# An overview of safeguard challenges and opportunities for small modular reactors

**Speaker: T. Aljuwaya**

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**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 12: Safeguards for SMRs (C.12)

**INDICO Abstract ID: 174**

## Abstract

Small Modular Reactor (SMR) technology is gaining momentum for its ability to provide reliable, eco-friendly, and cost-efficient energy solutions. However, its adoption presents distinct challenges and opportunities at the intersection of technological innovation and regulatory considerations. This review explores key aspects, such as the nuanced discussion of proliferation risk, challenges in safeguards implementation, resource constraints, exploration of novel technologies and designs, and the necessary adaptation of existing frameworks. SMRs pose challenges due to their inherent characteristics, including potential concealability and intricate designs. The need to tailor existing safeguards frameworks to accommodate these features adds complexity, exacerbated by resource constraints hindering effective implementation. Despite these challenges, SMR technology offers opportunities to enhance nuclear safeguards. Proliferation-resistant fuel cycles, self-contained fuel designs, standardized reactor designs, and remote monitoring technologies are avenues to fortify safeguards. International cooperation is crucial in navigating SMR challenges and maximizing benefits. Sharing best practices, collaborative technological advancements, and exchanging critical information are essential for a cohesive global approach. Advanced remote monitoring and data analytics become indispensable in this new era of safeguards technology, overcoming resource constraints and facilitating the adaptation of frameworks to novel SMR designs. In conclusion, while SMR technology introduces

challenges, it also presents avenues for substantial progress. Emphasizing opportunities to enhance proliferation resistance, streamline implementation, and foster international collaboration is vital. The global community's concerted efforts are essential for the secure and responsible deployment of SMRs within the evolving future energy mix, striking a strategic balance between technological advancements and rigorous safeguards measures.

# Nuclear safeguards assessments of molten salt reactor spent fuel

**Speaker: V. Mishra**

Primary Author: Vaibhav Mishra [1]

Co-Authors: Erik Branger [1]; Zsolt Elter [1]; Sophie Grape [1]; Sorouche Mirmiran [2]; Debora Trombetta [3]

*[1] Uppsala University; [2] Seaborg Technologies; [3] KTH*

**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 12: Safeguards for SMRs (C.12)

**INDICO Abstract ID: 197**

**Abstract**

Molten salt reactors are a novel reactor design concept where the fuel is often used in a molten form. These reactors are believed to be safer and more efficient than the conventional light water reactors operating today. They also differ significantly in their design and operation and pose unique safeguards challenges many of which remain to be overcome. Some of these challenges arise from the fact that the safeguards guidelines that exist today apply mainly to itemizable fuel whereas nuclear material from these advanced reactors is usually in a molten matrix form. A deeper understanding of these aspects applied to molten spent fuel is imperative to effectively implement safeguards measures for these reactors. Traditional safeguards guidelines and practices may not be directly applicable and could require significant changes, something which motivates research on this topic. Over the last two years, under a collaboration, researchers at Uppsala University have investigated nuclear safeguards-related challenges of molten salt reactors using the Compact Molten Salt Reactor developed by Seaborg Technologies as an example. The concept is envisioned to be an alkali-fluoride fueled reactor that can be placed on a transportable floating barge designed specially to house one or more units of this reactor. We present here results on assessments of material attractiveness of molten salt fuel using a newly formulated metric, the development of fuel isotopics datasets and implementation of machine learning algorithms for the prediction of salt's burnup, enrichment, and cooling time. This

paper sheds some light on the research that has already been done and the ongoing and future work planned for floating type molten salt reactors in general.

# Systematic proliferation resistance analysis of Small Modular Reactor designs

**Speaker: R. Rossa**

Primary Authors: Alessandro Borella [1]; Damien Gerard [2]; Greet Maenhout [3]; Riccardo Rossa [1]; Matthias Vanderhaegen [4]; Klaas Van Der Meer [5]

*[1] SCK-CEN; [2] ENGIE group; [3] Ghent University; [4] Federal Agency Nuclear Control/University of Ghent; [5] SCK.CEN*

**Presentation Type: Poster**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 12: Safeguards for SMRs (C.12)

**INDICO Abstract ID: 198**

**Abstract**

Small Modular Reactors (SMRs) are defined by the IAEA as nuclear reactors with a power capacity up to 300 MW(e). More than 80 SMRs designs have been proposed by different vendors and the IAEA Advanced Reactors Information System (ARIS) database contains information about 49 SMRs designs. Starting from the ARIS database, we conducted a systematic proliferation resistance analysis of a set of SMRs designs using the Proliferation Resistance and Physical Protection (PR&PP) methodology. Only SMRs with a detailed design were considered for the analysis to ensure that enough safeguards-relevant information is available. Each selected SMR design was evaluated with the PR&PP methodology in terms of proliferation technical difficulty, cost, time, material type, and detection resource efficiency. In addition, a comparison between SMR designs and current light water power reactors was made in term of safeguards inspection effort. The PR&PP analysis showed that most of the SMR designs achieve a proliferation resistance similar to current light water power reactors, although some points of attention emerge for some technology.

# Safeguards by design: preparing for Small Modular Reactors

**Speaker: J. Whitlock**

Primary Authors: Jae-sung Lee [1]; Traci Newton [1]; Jeremy Whitlock [1]

*[1] IAEA*

**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 12: Safeguards for SMRs (C.12)

**INDICO Abstract ID: 300**

**Abstract**

Safeguards are a set of technical measures applied by the IAEA on nuclear material and activities, through which the IAEA seeks to independently verify that nuclear facilities are not misused, and nuclear material not diverted from peaceful uses. States accept these measures through the conclusion of safeguards agreements with the IAEA, applicable for most States to all nuclear source or special fissionable material in all peaceful nuclear activities within the State's territory, under its jurisdiction, or carried out under its control anywhere. The IAEA's capability to implement safeguards on new nuclear technology must be ready before the technology is deployed. The innovative and evolutionary technologies proposed in several small modular reactor (SMR) designs will introduce unique safeguards challenges. This suggests the need for early awareness of the technology design, requiring direct engagement with design companies – a challenging prospect given the IAEA's limited resources and the number and variety of SMR designs in development. The process of early consideration of safeguards in the design process is known as safeguards by design (SBD). SBD can not only avoid costly retrofitting of safeguards equipment or modified facility features after construction, but also potentially improve the efficiency of safeguards implementation throughout the life of a facility, thus reducing the burden on all stakeholders (operator, State authorities, IAEA). To manage the SBD process with SMRs, the IAEA has initiated tasks with several Member State Support Programmes that allow direct engagement with SMR design companies, with the goal of facilitating timely deployment and efficient safeguards implementation during operation. The paper will summarize the status of this project, including lessons learned, next steps and future needs, as the IAEA works with Member States to jointly prepare for the timely and secure deployment of SMRs.

# Canada's safeguards readiness for small modular and advanced reactors

**Speaker: M. Kent**

Primary Author: Michael Kent [1]

*[1] Canadian Nuclear Safety Commission*

**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 12: Safeguards for SMRs (C.12)

**INDICO Abstract ID: 304**

**Abstract**

The Canadian Nuclear Safety Commission (CNSC), as Canada's safeguards regulatory authority, continues to ensure its readiness for the effective and efficient implementation of safeguards at small modular reactors (SMR). Canada has decades of experience in applying safeguards to CANDU reactors, uranium bulk handling facilities, and research and development, and hopes to leverage this knowledge in the application of safeguards for these novel designs and technologies. These efforts include its pre-licensing vendors design reviews, participation in the Member State Support Program task on safeguards-by-design for SMRs, and submission of preliminary design information for its first SMR. The CNSC has engaged with vendors, applicants, and the International Atomic Energy Agency to consider appropriate safeguards concepts, approaches, techniques, and equipment for these new designs. This paper will provide the status of SMR licensing applications in Canada, an overview of the CNSC's engagement on safeguards-by-design in various forums, efforts to integrate safeguards with safety and security, lessons learned and remaining challenges.

# U.S. – U.K. Bi-Lateral Collaboration on a Material Flow Safeguards Analysis for a Nominal Molten Salt Reactor Design

**Speaker: R. Smith**

Primary Author: Logan Scott [1]

Co-Authors: Ruth Smith [2]; Bego Aranguren [2]; Kees Jan Steenhoek [3]; Liberty Timewell [4]; Mat Budsworth [5]; Seddon Atkinson [5]; Mike Edmondson [5]

*[1] Oak Ridge National Laboratory; [2] U.S. National Nuclear Security Administration; [3] Oberon Three; [4] U. K. Department of Energy Security and Net Zero; [5] U.K. National Nuclear Laboratory*

**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 12: Safeguards for SMRs (C.12)

**INDICO Abstract ID: 399**

**Abstract**

Advanced and small modular reactor technologies have an immense potential to change power generation strategies worldwide. However, by utilizing advanced fuels and design elements, these same technologies present novel challenges for securing and safeguarding nuclear materials, requiring innovative solutions. Molten salt reactors (MSR) represent one of the most challenging reactor design classes, using fuel dissolved in the coolant to form a homogenous mixture that continuously circulates through the reactor system. Future deployment and export of MSRs must be accompanied by effective and efficient safeguards approaches and must meet the high precedent set by the IAEA to ensure that global proliferation risks are mitigated. In anticipation of this challenge, the United States Department of Energy's National Nuclear Security Administration and United Kingdom's Department for Energy Security and Net Zero recognize the need for cooperation and technical exchange to address challenges relevant to IAEA safeguards. This conference paper will present collaborative efforts to define key MSR design features and discuss their impact within a nuclear material safeguards context. While this work is not meant to provide a comprehensive solution to all anticipated safeguards challenges with MSRs, it should elicit dialogue and provide a framework for future work.

# U.S. – Canada Cooperative Nuclear Facilities and Safeguards Experience (NFASE)


**Speaker: Kj. Steenhoek**

Primary Author: Bego Aranguren [1]

Co-Authors: Ruth Smith [1]; Kees Jan Steenhoek [2]; Logan Scott [3]; Michael Kent [4]

*[1] U.S. National Nuclear Security Administration; [2] Oberon Three; [3] Oak Ridge National Laboratory; [4] Canadian Nuclear Safety Commission*



**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 12: Safeguards for SMRs (C.12)

**INDICO Abstract ID: 400**



**Abstract**

The U.S. Department of Energy's Office of Nonproliferation and Arms Control collaborated with its partners in Canada to advance awareness and acceptance of safeguards for Advanced and Small Modular Reactors (A/SMRs). During cooperative technical exchanges, several U.S. based A/SMR developers and vendors participated in a Nuclear Facilities and Safeguards Experience (NFASE), where they learned how the IAEA works with state regulators to apply safeguards in non-nuclear weapons states. Vendors learned that considering operational safeguards requirements early in the design and production process (safeguards by design, or SBD) can mitigate additional cost or design changes necessary to comply with international requirements. Building on Canadian expertise with developing safeguards methods for on-line refueled reactors, these technical exchanges allowed designers that intend to use circulating fuel, like molten salt or pebble-based fuels, to interact with subject matter experts and regulators with knowledge of similar accountancy methods. In addition, participants learned that early engagement with customers and local regulators is key to identifying and mitigating development and deployment risks. This paper will share impressions from participants of these cooperative efforts, identify lessons learned from international collaborations between U.S. and Canadian partners, and discuss how these exchanges contributed to the strategic objectives of each partner.

# Identify Technical Challenges in Safeguards Measurements of Advanced Small Modular Reactor Fuel Elements

**Speaker: J. Hu**

Primary Author: Jianwei Hu [1]

Co-Authors: Donny Hartanto [1]; Robert Mcelroy [1]

*[1] Oak Ridge National Laboratory*

**Presentation Type: Oral**

**Group:** Topical Group C: Safety, Security and Safeguards

**Track:** Track 12: Safeguards for SMRs (C.12)

**INDICO Abstract ID: 410**

**Abstract**

Advanced small modular reactor (SMR) designs use various nuclear fuel element types that can be significantly different than conventional light water reactor (LWR) fuels, including differences in size, composition, and chemical form (e.g., oxide, carbide, metallic). Nearly all the proposed advanced fuels use high-assay low-enriched uranium (HALEU), which can have much higher enrichments than those of LWR fuels (currently limited to < 5 wt.% 235U). The overarching goal of this work is to identify the potential technical challenges in safeguards verification measurements of these advanced fuel elements. This paper focuses on using modeling and simulation to assess (1) the performance of the existing instruments that are commonly used for safeguards measurements of advanced fuel elements, (2) how such performance for advanced fuel elements differs from that for LWR fuel elements, and (3) the potential challenges of using the existing instruments in meeting technical safeguards objectives for the advanced fuel elements. This paper will first present simulation results of safeguards measurements of select fresh advanced fuel elements (e.g., pebble, prismatic fuel bundle, and metal fuel bundle) using commonly-applied safeguards instruments including a high-purity germanium (HPGe) gamma detector, Uranium Neutron Coincidence Collar (UNCL) – II, and Fast Neutron Collar (FNCL). Results will also be presented for irradiated advanced fuel elements using a fork detector, which has been a primary instrument for spent fuel safeguards measurements. The performance of these instruments for advanced fuel elements are then compared with that of LWR fuel elements and the potential safeguards challenges of the advanced fuel elements are

summarized and discussed. Such findings are expected to be useful to the safeguards community and the SMR developers as new or alternative safeguards technologies can take a long time to develop and mature.

# Topical Group D: Considerations to Facilitate Deployment of SMRs

**Participating Member States and International Organizations:**

Algeria, Belgium, Brazil, Bulgaria, Canada, Czechia, Colombia, Egypt, Estonia, European Commission, France, Germany, Ghana, Hungary, IAEA, India, Indonesia, Iran, Iraq, Italy, Japan, Jordan, Kenya, Libya, Malaysia, Mali, Mongolia, Netherlands, Nigeria, Norway, Poland, Republic of Korea, Romania, Russian Federation, Saudi Arabia, Senegal, Slovenia, South Africa, Sweden, United Republic of Tanzania, United States, Viet Nam, WANO, WNA

Key Words: safety, study, heat, iaea, scenario, deployment, model, regulatory, infrastructure, generation

## Track 13: SMRs in Energy Planning for Climate Change Mitigation (D.13)

# Past, present and future of nuclear energy in Colombia from the deployment of SMRs


**Speaker: H. Llanes**

Primary Author: David Galeano [1]

*[1] Universidad Nacional de Colombia*


**Presentation Type: Poster**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 13: SMRs in Energy Planning for Climate Change Mitigation (D.13)

**INDICO Abstract ID: 2**


### Abstract

This presentation delves into the evolving role of nuclear energy, particularly Small Modular Reactors (SMRs), in Colombia's electrical sector. It addresses the country's increasing energy demands against the backdrop of climate challenges and the limitations of traditional hydroelectric power and intermittent renewable sources like solar and wind energy. Nuclear energy, especially SMRs, is presented as a viable, robust, and sustainable solution. The historical context of nuclear energy in Colombia is explored, charting its evolution and the shift towards sustainable nuclear technologies. The focus then shifts to the technical feasibility of integrating SMRs into the National Interconnected System (SIN), highlighting their scalability, safety, and operational flexibility. SMRs are especially suitable for areas where large nuclear plants are impractical, providing a stable electricity supply and complementing renewable sources. The future potential of microreactors in remote areas like La Guajira and the Amazon is also highlighted, considering their ability to tackle geographical and infrastructural challenges, support autonomous operations, and contribute to water desalination and local living conditions. The presentation concludes by envisioning the role of nuclear energy in decarbonizing Colombia's electricity sector, including repurposing existing infrastructures like coal plants. This strategic shift towards nuclear power aligns with international commitments like the Paris Agreement and enhances Colombia's global energy standing. Additionally, the innovative concept of 'pink hydrogen' production using

nuclear technology is examined. The potential of pink hydrogen in storage, transportation, and industrial applications is discussed, positioning Colombia as a leader in sustainable and innovative energy solutions while fulfilling its climate change commitments.

# Relationship between SMR and Planetary Boundaries: A mitigation strategy for the global environmental crisis

**Speaker: C.a. Prieto Valderrama**

Primary Author: Camilo Prieto Valderrama (pontificia Universidad Javeriana) [1]

*[1] Pontificia Universidad Javeriana (Colombia)*

**Presentation Type: Poster**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 13: SMRs in Energy Planning for Climate Change Mitigation (D.13)

**INDICO Abstract ID: 8**

## Abstract

**Relationship between SMR and Planetary Boundaries: A mitigation strategy for the global environmental crisis** Scientific evidence indicates that of the 9 planetary boundaries that have been defined, 6 have been exceeded. High CO2 emissions, land use change, disturbance of nitrogen and phosphorus cycles, damage to the integrity of the biosphere, the effects on fresh water and the excessive emergence of new entities are the geophysical bases of the global environmental crisis [(Richardson, 2023)][1]. In this article, we analyze the future potential of SMRs modular reactors in mitigating the global environmental crisis and its beneficial relationship with planetary boundaries.We calculate the m2/MWhy indicator related to the areal intensity and we find that SMRs can require between 0.06 m2/MWhy to 0.07 m2/MWhy. Additionally, the life cycle (LCA) of the SMR is reviewed, comparing its variables with other types of generation sources [(Vinoya, 2023).][2] Annually, fossil fuel emissions are responsible for the deaths of 1 million people in the world. The nuclear energy industry is the only one in its field that is responsible for waste management and the emissions associated with its activity have a low impact on air quality [(Freese, 2022)][3]. The implementation of SMRs in various non-interconnected populations in LATAM, where energy based on coal or liquid fuels is still generated, can be a very relevant step [(UPME, 2022).][4] Additionally, the desalination with SMR can improve access to drinking water in communities vulnerable to climate change [(Al-Othman, 2019)][5] In conclusion, SMRs are technologies that contribute to facing the global environmental crisis beyond reducing CO2 emissions. They achieve more efficient use of the land, demand less natural resources than other generation sources and are a tool to improve air quality and the availability of drinking water. [1]: https://doi.org/10.1016/j.energy.2023.128204 [2]: https://www.mdpi.com/1996-

1073/16/7/3224 [3]: https://doi.org/10.1038/s41560-023-01241-8 [4]: https://www1.upme.gov.co/DemandayEficiencia/Documents/PEN_2020_2050/Actualizacion_PEN_2022-2052_VF.pdf [5]: https://doi.org/10.1016/j.desal.2019.01.002

# Evaluation of Potential Locations for Siting Small Modular Reactors in Iraq to Support Clean Energy Goals

**Speaker: M.d. Shnawa**

Primary Author: Dr.muataz Shnawa [1]

Co-Author: Hayder Mohamed [1]

*[1] Iraqi Atomic Energy Commission*

**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 13: SMRs in Energy Planning for Climate Change Mitigation (D.13)

**INDICO Abstract ID: 17**

**Abstract**

the study contains the feasibility of small modular reactors and an assessment of the site selection process for small modular reactors in Iraq to produce electrical energy to contribute to solving the problem of shortage of electrical energy in Iraq, where Iraq needs (35000) MW to meet the actual need for energy while the total production (24000) MW and Iraq seeks to diversify the sources of power generation and reduce the bill Fossil fuels and reducing greenhouse gas emissions resulting from power generation, where the need arose in remote areas for small power plants.Where work was done within the work methodology to choose sites for establishing a standard reactor station, which is based on scientific literature published in the field of earth sciences, water resources, environment, climate, satellite images, geological, topographical and hydrological maps, etc. And adopting projective standards according to the literature of the International Atomic Energy Agency. And working on advanced scientific programs such as (GIS). These programs were used to analyze satellite and digital images to choose the best sites. The first revealed multiple sites in different governorates of Iraq, including (7) sites in Babil Governorate. (5) sites in Diwaniyah Governorate, (3) sites in Muthanna Governorate, and (3) sites in Najaf Governorate, where a comparison was made between them in terms of describing their geographical locations and their distance from the center of the governorate, as well as the area available for each site, the type of available water source, and proximity to transmission lines. Energy and population density of the areas and their surroundings, as well as the topography of the nominated areas, and the best reality was in Babil Governorate.

# Small Modular Reactors in the Petroleum Industry: A Sustainable Solution for Enhanced Operations

**Speaker: A. Rahimian**

Primary Author: Aref Rahimian (nuclear Science And Technology Research Institute) [1]

*[1] Nuclear Science and Technology Research Institute (NSTRI)*

**Presentation Type: Poster**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 13: SMRs in Energy Planning for Climate Change Mitigation (D.13)

**INDICO Abstract ID: 19**

**Abstract**

One of the most important factors in creating enthusiasm in oil-rich countries for the use of SMRs is to find possible applications of these reactors in the oil industry. Refinery industries are very energy-intensive and, in some cases, require a power plant of up to tens of megawatts. On the other hand, in the areas where these refineries exist, environmental pollution is very high, and the health of employees is very dangerous. Therefore, it is very important to use a clean energy source. A small-scale modular reactor can be one of the best options. In this article, an attempt is made to investigate the effects of using this reactor on reducing the amount of carbon released into the surrounding air.

# Efficiency assessment of SMR development as a non-carbon energy source in the Russian electricity and district heat supply systems

**Speaker: F. Veselov**

Primary Author: Fedor Veselov (energy Research Institute, Russian Academy Of Sciences) [1]

Co-Authors: Andrey Khorshev (energy Research Institute, Russian Academy Of Sciences) [1]; Tatiana Novikova (energy Research Institute, Russian Academy Of Sciences) [1]; Tatiana Pankrushina (energy Research Institute, Russian Academy Of Sciences) [1]

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**Presentation Type: Poster**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 13: SMRs in Energy Planning for Climate Change Mitigation (D.13)

**INDICO Abstract ID: 29**

**Abstract**

The paper discusses economic and technical possibilities and limitations of the SMR development in large and small-scale power systems in Russia, incl. Arctic regions with distributed electricity and heat loads. The results of the economic comparison of SMRs with alternative conventional and low-carbon (CCS) thermal power plants and RES are presented. The assessment takes into account the technological learning rates as well as the cost of integrating power plants into the power system. The analysis of SMR competitiveness was extended to coal and gas co-generation (CHP) technologies, as well as to alternative combinations of heat boilers (fossil and electric) with various sources of electricity. The sensitivity analysis made it possible to estimate the target levels of SMR cost reduction and support measures (including carbon payments), which are necessary for their mass deployment. Optimization of the low-carbon transformation of the Russian electricity and district heat supply systems allowed investigating the effective scales of SMR development on the horizon up to 2050. The optimization took into account various levels of carbon emission quotas. The impact of carbon payments on the efficiency of fuel substitution and the development of nuclear power, including SMRs, was also studied.

# Harnessing the Potential of Small Modular Reactors for Climate Change Mitigation through Energy-Mix Optimization and Hydrogen Generation

**Speaker: A. Salman**

Primary Author: Ahmed E. Salman [1]

*[1] Egyptian atomic energy authority*

**Presentation Type: Poster**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 13: SMRs in Energy Planning for Climate Change Mitigation (D.13)

**INDICO Abstract ID: 35**

## Abstract

Small modular reactors (SMRs) are gaining attention as potential contributors to climate change mitigation, particularly in hydrogen generation. SMRs are smaller and more flexible than traditional nuclear reactors, allowing for deployment in diverse locations and integration into existing energy infrastructure. They offer low-carbon electricity, reducing reliance on fossil fuels and supporting grid integration. This clean electricity can power electrolyzers for hydrogen production, aiding decarbonization in transportation, industry, and heating. The high-temperature gas-cooled SMRs also offer a reliable and continuous source of heat, which can be efficiently utilized for producing hydrogen using thermolysis through different processes. SMRs have inherent safety features, standardized manufacturing, and simplified construction, potentially reducing costs and timelines. They can provide continuous power with a smaller footprint, benefiting remote communities and industries. However, deploying SMRs for energy planning and hydrogen generation requires considerations such as regulatory frameworks, public acceptance, waste management, and non-proliferation. Economic viability and scalability must also be assessed compared to alternative low-carbon energy solutions. Careful consideration of various factors is necessary to ensure the safe and sustainable deployment of energy systems. In this work, the IAEA-MESSAGE code is used to model the energy-supply systems to determine the optimum energy-mix technology in addition to the hydrogen demand to meet future energy demands in the country.

# Application of SMART to Achieve Net Zero Emissions

**Speaker: J. H. Moon**

Primary Author: Joo Hyung Moon [1]

*[1] Korea Atomic Energy Research Institute*

**Presentation Type: Poster**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 13: SMRs in Energy Planning for Climate Change Mitigation (D.13)

**INDICO Abstract ID: 51**

**Abstract**

SMART (System-integrated Modular Advanced ReacTor) is an advanced integral reactor developed by Korea Atomic Energy Research Institute. It is empathized that technologies implemented in SMART had been proven through comprehensive technology validation programs. Therefore, SMART can be deployed immediately. Alberta’s oil sands plants are dependent on natural gas to meet requirements of steam and electricity. However, they emit huge amount of greenhouse gas. SMART can provide carbon-free heat and/or power for oil sands operations. If SMART is built in Alberta, it can significantly contribute to net zero emissions in oil sands industries. Multiple units of SMART are expected to be built in Alberta, which also contributes to job creation and GDP increase in Alberta. Furthermore Canada will play a leading role in the emerging SMR market. In this presentation, design characteristics of SMART will be briefly provided and recent activities to deploy SMART in Canada are also presented.

# Non-electric Application of Nuclear Energy in Korea

**Speaker: J. Lee**

Primary Author: Jihyeon Lee [1]

*[1] Korea Atomic Energy Research Institute*

**Presentation Type: Poster**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 13: SMRs in Energy Planning for Climate Change Mitigation (D.13)

**INDICO Abstract ID: 56**

**Abstract**

Nuclear energy has been considered as a carbon-free alternative of the unabated fossil fuels for electric and non-electric applications. To replace various kinds of energy consumption with it, a nuclear reactor is required to be multipurposable. A small modular reactor (SMR) has an advantage in a site flexibility, which is possible to construct the unit near a demanded site. The application of SMR as a energy source make possible to achieve a carbon-free or carbon-less energy consumption instead of the conventional petrochemical-based one. In recent, Korea struggles to secure a renewable energy source for maintaining the socioeconomic development. The government endeavors to reduce the emission of green house gas in a industrial part, which is almost 62% of the national energy demand. The amount of own renewable energy source is limited in Korea. In addition, the total production of green hydrogen is still lacking compared to significant requirements in global countries, so it is hard to import all national demand of green energy as a green hydrogen. In this context, the integration of SMR with a industrial complex can be a viable suggestion for relieving a burden on the carbon-tax and balancing the energy mix along with the renewable energy. Herein, The overall demand for a thermal source on the industrial complex, which include a petrochemical complex and a steel industry in Korea, is discussed. It will introduce the application of a gas-cooled reactor as a thermal source for a industrial complex, especially for producing hydrogen such as a reforming or other process.

# Integrating Small Modular Reactors (SMRs) into Nigeria's Energy Mix. Prospect toward near-term deployment.

**Speaker: R. Soja**

Primary Author: Reuben Soja

**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 13: SMRs in Energy Planning for Climate Change Mitigation (D.13)

**INDICO Abstract ID: 67**

**Abstract**

With a population of over Two Hundred and Twenty Three (223) million, Nigeria remains the most populated country in Africa and the sixth-largest exporter of crude oil in the world. The country has a total installed capacity of 12,522MWe, with 83% contribution from fossil fuels, 14% from hydropower and 3% from solar and other sources. The country has been experiencing a lingering energy crisis that has negatively influenced industrialization and hindered its efforts toward achieving sustainable economic growth. Due to the frequent power outages and the need for self-generation by the industry and other stakeholders, Nigeria has made it necessary to include nuclear power into the country's energy mix and has made tremendous progress towards building nuclear power infrastructure. However, considering the realistic economic situation and high construction cost associated with large scale nuclear reactors, such commitment is experiencing some delay because of dwindling economic situation. Nuclear industry expert's inventiveness on Small Modular Reactors (SMRs) serves as a means of ensuring that both low and middle-income countries featured in the drive towards including nuclear energy in the country's energy mix as a step towards combating the devastating effects of climate change. Such SMRs offers numerous benefits when compared to large-scale nuclear reactors, in addition to its non-electrical applications. The focus of this present study is on near term deployment of SMRs into the country's energy mix thereby boasting sustainable economic growth. With the help of IAEA energy modeling tool, Model for Energy Supply Strategy Alternatives and their General Environmental impacts (MESSAGE), analysis of various country's energy resources will be perform thereby presenting the need for integrating SMRs towards boosting industrialization and promoting economic growth. The result of the analysis will present optimal deployment strategies of SMRs into the country's energy mix.

# The Role of Small Modular Reactors (SMRs) in Mitigating Climate Change and Promoting Economic Growth in Africa – A Case Study of Nigeria

**Speaker: A. Ibrahim**

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**Presentation Type: Poster**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 13: SMRs in Energy Planning for Climate Change Mitigation (D.13)

**INDICO Abstract ID: 70**

## Abstract

Small Modular Reactors (SMRs) are increasingly viewed as a promising solution to meet the rising energy needs in Africa. They offer cost-effective, financially feasible, and quicker completion options compared to traditional methods. Furthermore, SMRs hold the potential to address critical challenges such as fostering economic development and mitigating climate change. This study investigates the role of SMRs in electricity generation, combat climate change, their potential to spur economic growth. The focus is specifically on Nigeria, serving as a case study. In 2019, Africa accounted for around 4% of global $CO_2$ emissions, with the largest contributors being South Africa, Nigeria, and Egypt due to their significant industrial and energy sectors. Achieving the pace of $CO_2$ emissions reductions in line with the Paris agreement requires large increases in efficiency and renewable investment. Investments in SMRs will contribute to climate change mitigation by reducing reliance on fossil fuels and lowering greenhouse gas emissions associated with electricity generation SMRs present numerous advantages over conventional large-scale nuclear reactors. These include lower initial costs, improved safety features, and scalability, which are especially beneficial for addressing the challenges posed by poor and inadequate grid systems in Africa. Consequently, by offering a reliable and sustainable source of electricity and will help countries in Africa meet their climate targets under international agreements while promoting the transition to a low-carbon economy. . Using Nigeria as a case study, this paper analyzes the potential benefits and addresses challenges of developing and deploying SMRs in the energy mix in Africa. It provides insights into policy implications, financing, operation,

and maintenance, as well as recommendations for maximizing the socio-economic and environmental benefits of SMRs in the region. Overall, SMRs offer a promising pathway towards sustainable development in Africa, with significant implications for energy security, economic prosperity, and environmental sustainability to achieve Net Zero

# NUCLEAR POWER, AN OPPORTUNITY FOR DEVELOPMENT IN AFRICA


**Speaker: A. Dicko**

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**Presentation Type: Poster**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 13: SMRs in Energy Planning for Climate Change Mitigation (D.13)

**INDICO Abstract ID: 75**


**Abstract**

More than 640 million people in Africa do not have access to electricity. Experts reveal that the rapid proliferation of small modular reactors could transform the evolution nuclear energy in Africa. A sall modular reactor (SMR) is a nuclear fission reactor, smaller in size and power than conventional reactors, manufactured in a factory and transported to the installation site for installation. Modular reactors make it possible to reduce work on site, increase the efficiency of containment and the safety of nuclear materials. SMRs (with a power of 10 to 300 MW) are offered as a lower-cost alternative, or as a complement, to conventional nuclear reactors. Africa has significant potential in nuclear energy According to 2022 data from the World Nuclear Association, four African countries, namely Namibia, Niger, South Africa and Malawi, stand out as major uranium producers. A real boon for improving people's access to electricity, but also for meeting the challenge of climate change, according to experts. The International Atomic Energy Agency estimates that nuclear power has avoided more than 70 gigatons of carbon emissions over the past five decades and continues to avoid more than a gigatonne per year. Additionally, replacing 20% of coal-fired electricity generation with 250 gigawatts of nuclear power generation would reduce emissions by 2 gigatons of CO2, or 15% of electricity sector emissions per year. On the continent, only South Africa currently has a nuclear power plant. Yet experts say the new generation of reactors makes nuclear power accessible to more African countries, offering lower cost, faster construction and improved safety. WHO data shows that 3.2 million people die each year from conditions caused by the use of polluting fuels and technologies, hence the urgent need to look at

nuclear power as a reliable energy source and durable. Keywords: reactor, fission, power, Africa, reliable.

# SMRs in Brazil: A Paradigm Shift in Energy Policy for Climate Mitigation

**Speaker: A. Carvalho**

Primary Authors: Amanda Carvalho [1]; Elaine Rodrigues [2]; Delvonei Alves De Andrade [1]; Jose Oscar William Vega Bustillos [1]

*[1] IPEN; [2] IPEN/IPA*

**Presentation Type: Poster**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 13: SMRs in Energy Planning for Climate Change Mitigation (D.13)

**INDICO Abstract ID: 86**

**Abstract**

Brazil is an extremely important country regarding climate change, both because it is one of the biggest GHG emitters in the world and because it has the means to mitigate these emissions. Brazil has considerable emissions in the energy sector, and power plants that burn either coal or natural gas are increasingly being used to meet energy demand in periods of drought to make up for insufficient hydroelectric production. With the worsening of droughts due to the impacts of climate change, the energy sector is likely to be heavily impacted; in 2023, several regions of Brazil suffered blackouts due to a lack of energy supply. SMRs could represent a viable solution to the problems facing the Brazilian energy sector. The use of a wide variety of energy sources is fundamental to decarbonizing the energy matrix. To decarbonize energy systems efficiently and with the necessary urgency, the sources need to be diversified and climate-resilient. When considering the delay and bureaucracy involved in building nuclear power plants in Brazil (the most recent, Angra 3, began construction in 1984 and is still not finished), it's understandable why Brazilian public policies have given less importance to nuclear energy. Because their installation is quicker, cheaper, and less bureaucratic, SMRs key to decarbonizing energy production in Brazil, replacing the construction of new coal or natural gas power plants, and being allocated to meet local demands. They can also be implemented as part of state policies, rather than federal ones. This study seeks to understand Brazilian energy policy and suggest alternatives for the efficient introduction of SMRs in Brazil.

# The TANDEM Euratom project to study the integration of SMRs into low-carbon hybrid energy systems: mid-term progress

**Speaker: C. Vaglio-gaudard**

Primary Author: Claire Vaglio-gaudard [1]

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**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 13: SMRs in Energy Planning for Climate Change Mitigation (D.13)

**INDICO Abstract ID: 89**

**Abstract**

Authors: C. Vaglio-Gaudard et al. The TANDEM project (2022-2025) is a European Commission initiative funded under the Euratom program. The main goals of TANDEM are to: - Develop an integrated vision of energy systems through the implementation of Hybrid Energy Systems (HESs) incorporating Small Modular Reactors (SMRs) to produce heat, electricity and hydrogen, - Develop tools and methodologies to study these HESs, - Show the role/benefits of multipurpose SMRs integrated into these HESs for the energy transition. Considering SMR near-term deployment in Europe, the project mainly focuses on light-water technologies. The project started 18 months ago. The goal of the paper is to present the mid-term progress of the project. The first activities carried out highlighted the stakes associated with the SMR deployment in Europe, directly linked with European energy policies as well as energy markets and their evolution. Thus the project provided the generic configurations of two HES to be studied, a District Heating configuration and an Energy Hub configuration, within two timeframes 2035 and 2050. These configurations constitute the input data necessary to start the safety and techno-economics studies in the project. They are studied in the light of three different European local contexts, in Finland and in Czech Republic for the first HES, and in France for the second HES.

# Techno-economic Analysis of SMR Deployment in the Estonian Power System

**Speaker: R.h. Ivask, A. Tkaczyk**

Primary Authors: Roald Heinrich Ivask [1]; Alan Tkaczyk [1]; Mario Tot [2]; Henri Paillere [2]

*[1] University of Tartu; [2] IAEA*

**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 13: SMRs in Energy Planning for Climate Change Mitigation (D.13)

**INDICO Abstract ID: 91**

**Abstract**

Energy production in Estonia has heavily relied on fossil fuels, namely 70% of electricity generation in 2019 was powered by oil shale. Estonia has committed to contribute to joint EU greenhouse gas reduction targets. Estonia's Ministry of Climate, in order to ensure preparedness and resilience to react to the impact of climate change, has set a target to reduce Estonian greenhouse gas emissions by 80% by 2050. Recognizing this, the Estonian government's Nuclear Energy Working Group report published at the end of 2023 indicated that introduction of nuclear power into Estonia's energy system could significantly contribute to achieving climate neutrality goals. A suitable nuclear power option to consider could be a small modular reactor (SMR) with a capacity of 300-400 MW. To further assess techno-economic aspects of the nuclear option, the IAEA's energy system assessment tool MESSAGE was applied. A case study is being developed to understand how an SMR would integrate into the Estonian energy system, including regional grid and market considerations. Existing and planned power generation technologies were analyzed, including seasonal electricity and heat demand. Several scenarios were simulated for the period up to 2050. The paper summarizes the results and conclusions of this analysis.

# Feasibility study of a hybridization of small modular reactor with a solar power plant using molten-salt heat storage in Algerian south

**Speaker: M. Dougdag**

Primary Author: Mourad Dougdag [1]

Co-Authors: K. Attari [1]; M. Haddad [1]; M. Halla [1]; N. Mellel [1]; B. Mohammedi [1]; M. Salhi [1]; M. L. Yahiaoui [1]

*[1] CRNB/COMENA*

**Presentation Type: Poster**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 13: SMRs in Energy Planning for Climate Change Mitigation (D.13)

**INDICO Abstract ID: 105**

**Abstract**

Owing to the growing future energy security challenges on the national and international scale, it becomes necessary and urgent to set up a new and renewable energy policy in order to respond to the increasing demand for electric power. Quests that involve the exploring of all available resources of energy. Nowadays, in the world, there has been an increasing interest in green energy, which provides climate-friendly decarbonized electricity (neither greenhouse nor pollution effect). The coupling between renewable energies and nuclear energy can be a promising way to enhance renewable energy deficiencies and to reduce the dependency on fossil energy. While in Algeria, a country which conceals inestimable resources of solar energy, there is an increasing interest in renewable energy, while it seems that the coupling between solar and nuclear energy is weakly prospected. In order to explore such ways and to respond to the concerns of remote areas in southern Algeria not connected to the national electricity networks, our choice has been made on the hybridization of a very small modular reactor with a concentrated solar plant, taking into account the severe climatic environments of these regions. The present paper presents the results obtained from different hybridization configurations.

# Repurposing of coal power plants with Nuclear Methanol hybrid energy system – A South African case study


**Speaker: F. Panday**

Primary Author: Farisha Panday [1]

*[1] CSIR*


**Presentation Type: Poster**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 13: SMRs in Energy Planning for Climate Change Mitigation (D.13)

**INDICO Abstract ID: 108**

**Abstract**


As the world makes strides towards achieving climate goals and reducing carbon emissions, it is worthwhile to consider the opportunities of repurposing coal power plants that have been mothballed or are reaching it's end of life. Coal still dominates the South African energy mix by providing 80% of the total system load. Hybrid energy systems are perfect candidates to address the current energy demands by reducing carbon emission challenges caused by coal power plants. A Nuclear Methanol system is investigated as a proposed case study for the repurposing of a coal power plant with Small Modular Reactor (SMR) operation. Methanol is well known as 'liquid Hydrogen' which is more stable and less flammable and is thus a more attractive option because it presents much lower storage and transportation risk. Factors that need to be considered include, but not limited to, site zoning, multi-module plants, operational and safety challenges, regulatory and licencing challenges, etc. The viability of the hybrid energy system with specific focus on the South African landscape will be investigated along with the challenges and opportunities presented for the deployment of SMRs to the established sites. References: [1] Nils Haneklaus, Staffan Qvist, Paweł Gładysz, Łukasz Bartela, Why coal-fired power plants should get nuclear-ready, Energy, Volume 280, 2023, 128169, ISSN 0360-5442, https://doi.org/10.1016/j.energy.2023.128169

# The Role of Small Modular Reactors in Enhancing Global Energy Security: A Comparative Analysis of Deployment Strategies in Diverse Energy Markets

**Speaker: L. Guimarães [1]**

Primary Author: Leonam Guimaraes [2]

*[1] TBC; [2] Eletronuclear SA*

**Presentation Type: Poster**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 13: SMRs in Energy Planning for Climate Change Mitigation (D.13)

**INDICO Abstract ID: 128**

**Abstract**

The paper would explore the following facets: Global Energy Security Context: Examining the concept of energy security and its critical importance in the current global energy landscape. This part would contextualize the role of SMRs within the broader framework of energy needs, sustainability, and geopolitical factors affecting energy policies. Comparative Analysis of Deployment Strategies: Investigating various strategies for the deployment of SMRs across different energy markets, including developed and developing countries. This would involve an examination of case studies or hypothetical scenarios, assessing factors like economic feasibility, regulatory environments, and infrastructural readiness. Integration with Renewable Energy Systems: Exploring how SMRs can complement renewable energy sources, such as solar and wind, to create hybrid systems. This section would assess the potential of SMRs in enhancing the reliability and stability of renewable energy-based grids. Policy Implications and Recommendations: Offering insights into the policy frameworks necessary for the successful integration of SMRs into national and international energy strategies. This would include discussions on regulatory standards, international cooperation, and investment models. This topic not only aligns with current scientific and technological trends but also engages with broader socio-economic and policy-related discussions, making it a highly relevant and multidisciplinary subject for research.

# Comparative Assessment of Small Modular Reactors versus Large Nuclear Power Plants for Future Electricity Generation in Libya


**Speaker: T. Z. Malatim**

Primary Author: Tariq Malatim [1]

Co-Author: Mustafa Ben Ghzail [1]

*[1] Libyan Atomic Energy Establishment*


**Presentation Type: Poster**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 13: SMRs in Energy Planning for Climate Change Mitigation (D.13)

**INDICO Abstract ID: 138**


### Abstract

This study comprehensively investigates the potential adoption of Small Modular Reactors (SMRs) in Libya, contrasting their implementation with that of large nuclear power plants (NPPs). It conducts a comparative analysis encompassing various crucial aspects, including: **• Economic considerations:** The study evaluates the comparative capital costs, operational expenses, and long-term economic viability of both SMRs and large NPPs in the Libyan context. **• Workforce requirements:** An assessment is made of the workforce requirements for each technology, considering existing expertise and the need for potential training and development programs. **• Project timelines:** The study compares the expected construction and commissioning timeframes for each scenario, considering potential advantages of standardized modular construction offered by SMRs. Three distinct scenarios are investigated to provide a nuanced understanding of the potential applications of SMRs: **• Scenario 1:** This scenario assumes the construction of a single large NPP equipped with a VVER1200 reactor, situated in Sirt city, based on existing site selection studies. **• Scenario 2:** This scenario explores the deployment of multiple ACP100 SMRs, also utilizing Pressurized Water Reactor (PWR) technology, all located in Sirt. **• Scenario 3:** This scenario investigates the feasibility of implementing multiple SMR-based NPPs distributed geographically across Libya. The study outlines key factors to be considered when selecting suitable locations, including: **Geographic considerations**: Geological and environmental characteristics will be evaluated using data from national research

institutions. **Population proximity:** Siting near population centers will be prioritized to minimize transmission losses and maximize grid efficiency. **Water resources:** The study will assess the feasibility of utilizing the Great Man-Made River for water supply in regions with limited resources.

# POTENTIAL DEPLOYMENT OF A SMALL MODULAR REACTOR TO RUN THE STANDARD GAUGE RAIL NETWORK IN TANZANIA

**Speaker: S.f. Sawe**

Primary Author: Shovi Sawe [1]

Co-Author: Leonid Nkuba [1]

*[1] Tanzania Atomic Energy Commission*

**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 13: SMRs in Energy Planning for Climate Change Mitigation (D.13)

**INDICO Abstract ID: 148**

**Abstract**

The United Republic of Tanzania (URT) is currently expanding its rail network with the construction of a Standard Gauge Railway (SGR), spanning approximately 2,000 km from Dar es Salaam to Mwanza and Kigoma, and from there linking the URT to Rwanda, Burundi, and the Democratic Republic of the Congo. The SGR's operations will rely on electricity from The Tanzania Electric Supply Company (TANESCO). According to TANESCO, Tanzania faces power shortages due to various factors, including drought. Given the need for a reliable power supply for the SGR, Small Modular Reactors (SMRs) are being considered as an alternative source unaffected by drought, unlike hydropower. Reports indicate that Tanzania's power installed capacity is 1,938.35 MW as of December 31, 2023, with 63% from natural gas, 32% from hydropower, and 5% from diesel and biomass. With the ongoing climate change and the increasing power demand which is growing at a rate of 10-15% per year, the introduction of SMR in the energy mix is important. Clearly, the deployment of SMR in Tanzania will facilitate the implementation of the country’s sustainable industrial development policy and the country’s commitments to the Sustainable Development Goals. The potential for deploying SMR in Tanzania is assessed and reported.

# The green shift – extracting synergies from the oil and gas sector when establishing nuclear in Norway

**Speaker: N. Amosova**

Primary Author: Steffen O. Saele [1]

Co-Authors: Havard Kristiansen [1]; Sunniva Rose [1]; Natalia Amosova [1]; John Kickhofel [1]; Oyvind Aas-hansen [1]; Jonny Hesthammer [1]

*[1] Norsk Kjernekraft AS*

**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 13: SMRs in Energy Planning for Climate Change Mitigation (D.13)

**INDICO Abstract ID: 242**

**Abstract**

Today, the oil and gas sector is by far the main driver in the Norwegian economy but also a main contributor to Norway's CO2 emissions. To achieve the national goal of (close to) net zero emissions by 2050, it is of paramount importance to the Norwegian economy to identify and extract synergies from the oil and gas sector in the transition to competitive clean energy systems of the future. In the present paper we emphasise that investments in SMR technology can be an alternative to small- to medium sized oil and gas fields in Norway. SMRs may also play a crucial role in decarbonization and electrification of the oil and gas industry during the transition phase, while simultaneously enabling the use of process heat for CCS and the production of hydrogen and synthetic fuels. Further, similarities between the sectors may facilitate transfer of competence and work-force as well as supply chains between the industries while creating new business opportunities for the Norwegian oil and gas sector.

# ESFR-SMR Requirements to fit into the future EU electricity network

**Speaker: S. Perez-martin**

Primary Author: Sara Perez-martin [1]

Co-Authors: Evaldas Bubelis; Sebastian Ruck

*[1] Karlsruhe Institute of Technology*

**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 13: SMRs in Energy Planning for Climate Change Mitigation (D.13)

**INDICO Abstract ID: 254**

**Abstract**

This study reports various factors modulating the characteristics of the future EU electricity grid and therefore establishing a basis for the European Sodium Fast Reactor (ESFR) - Small Modular Reactor (SMR) requirements, namely: i) policy plans and programs of the EU Commission for 2050, including EU Green Deal and national climate targets, ii) low-carbon technologies available to achieve net-zero target and iii) methods for providing stability to the grid and grid power balance. The European Green Deal aims at transforming the EU into a modern, resource-efficient and competitive economy, ensuring no net emissions of GHG by 2050. The backbone of this transformation will be low-carbon technologies as well as large-scale European electrical network. Conventional power plants directly connected to high-voltage transmission lines via synchronous-rotating-alternator contribute to system stability. This option is absent for Variable Renewable Energies(VRE), although they can supply or absorb reactive power. The large VRE integration will stress the problem of maintaining voltage stability and new solutions have to be implemented to enhance the response of power electronics inverters. Methods for providing grid stability and supporting the power balance, such as flexible power operation and other grid stabilizers (e.g.fast frequency response technologies, kinetic energy supply systems and energy storage systems) are therefore required to low-carbon technologies including ESFR-SMRs. Existing requirements established for Nuclear Power Plants, both from the European Utilities Requirements association and Electric Power Research Institute as well as the best operational performance of currently designed advanced nuclear reactor systems are considered as

reference for ESFR-SMR operational requirements. In order to be competitive, ESFR-SMRs have to offer load-following capabilities at least equivalent to conventional SMRs. The integration of a Thermal Energy Storage system enables ESFR-SMR to provide wider load-following capabilities, while maintaining safe reactor operation. The publication belongs to ESFR-SIMPLE EU-project addressing the ESFR-SMR design (Grant-Agreement 101059543).

# Incorporating Small Modular Reactors with Solar and Wind for Ghana's Sustainable Energy Transition Beyond Conventional Nuclear Power Ambition Post-COP28

**Speaker: M.a. Nyasapoh**

Primary Author: Mark Amoah Nyasapoh (nuclear Power Institute, Ghana Atomic Energy Commission& Department Of Renewable Energy Engineering, School Of Energy, University Of Energy And Natural Resources) [1] [2]

Co-Authors: Nana Sarfo Agyemang Derkyi (department Of Renewable Energy Engineering, School Of Energy, University Of Energy And Natural Resources) [3]; Felix Ohene-fobih Ameyaw (nuclear Power Institute, Ghana Atomic Energy Commission) [4]; Archibold Buah-kwofie (nuclear Power Institute, Ghana Atomic Energy Commission) [4]; Seth Kofi Debrah (nuclear Power Institute, Ghana Atomic Energy Commission& School Of Nuclear And Allied Sciences, University Of Ghana – Legon) [5]; Hossam A. Gabbar (smart Energy Systems Lab, And Advanced Plasma Engineering Labfaculty Of Energy Systems And Nuclear Science, And Faculty Of Engineering And Applied Science Ontario Tech University, Canada) [6] [7]; Joshua Gbinu (nuclear Power Institute, Ghana Atomic Energy Commission) [4]; Samuel Gyamfi (university Of Department Of Renewable Energy Engineering, School Of Energy, University Of Energy And Natural Resourcesnergy And Natural Resources) [8]

*[1] GAEC; [2] UENR; [3] Department of Renewable Energy Engineering, School of Energy, University of Energy and Natural Resources (UENR); [4] Nuclear Power Institute, Ghana Atomic Energy Commission (GAEC); [5] Nuclear Power Institute, Ghana Atomic Energy Commission (GAEC) & School of Nuclear and Allied Sciences, University of Ghana – Legon; [6] SESL; [7] APEL; [8] University of Department of Renewable Energy Engineering, School of Energy, University of Energy and Natural Resources (UENR)nergy and Natural Resources*

**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 13: SMRs in Energy Planning for Climate Change Mitigation (D.13)

**INDICO Abstract ID: 267**

**Abstract**

Purpose: The paper explores integrating Small Modular Reactors (SMRs) with solar and wind energy as an alternative to conventional/traditional nuclear power plants/reactors for Ghana's sustainable energy transition post-COP28. Methods: The study employed a quantitative analysis to evaluate the effects of combining SMRs with solar and wind energy in Ghana's energy landscape using HOMER and the IAEA MESSAGE tool. Findings: The paper offers increased adaptability and expandability in fulfilling the nation's energy requirements. Thus, Ghana has a good chance to attain a sustainable energy mix by integrating SMRs with wind and solar power. Furthermore, this strategy lowers greenhouse gas emissions and the reliance on fossil fuels while improving energy security, grid stability, and resilience. Research Limitation/Implications: This study concentrates on the technical planning and elements of combining solar and wind energy with SMRs in Ghana. Hence, emphasis on the need for additional research on public acceptance, regulatory frameworks, and socio-political factors that affect adoption. Practical Implication: To speed up Ghana's energy transition after COP28, the study’s findings highlight the significance of investing in integrated energy infrastructure that combines SMRs with solar and wind energy. Such an infrastructure has the potential to improve energy security, promote sustainable development, and mitigate climate change.

# Global Coal Plant Potential for SMR Siting with the Case of Poland and Indonesia

**Speaker: J. Shin**

Primary Author: Jaejeong Shin [1]

Co-Author: Sunjin Kim [1]

*[1] Korea Energy Economics Institute*

**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 13: SMRs in Energy Planning for Climate Change Mitigation (D.13)

**INDICO Abstract ID: 285**

**Abstract**

The global goal of achieving carbon neutrality by 2050 has led to a push for carbon-free energy sources to replace fossil fuels. Small Modular Reactors (SMRs) have the potential to support this energy transition by repurposing retired coal plants. This study identifies the size of coal plants in 54 countries where replacement with an SMR is suitable in terms of site-screening criteria. Using population density, capable faults, floodplains, and peak ground acceleration as siting criteria, we find that 108 GW could be considered for SMR siting, out of the 899 GW of coal plants retiring (or retired) between 2021 and 2050. The U.S. has 62.4 GW of coal plants available for SMR siting, which is sufficient to cover its nuclear capacity requirements of the IEA's 2050 net-zero scenario (NZE), 13.8 GW. In China, 2.5 GW of coal plants could be suitable for SMR siting, which is less than its nuclear capacity requirements of NZE, 110.6 GW. Using a power planning optimization model (WASP), we also examine the feasibility of i-SMR (680 MW) in Poland and Indonesia, which have a high share of coal capacity. The results indicate that Poland and Indonesia can deploy 11 and 85 units of i-SMR, respectively, by 2050.

# Towards a Sustainable Future: SMR Smart Net Zero City

**Speaker: J. Kang**

Primary Author: Jinhui Kang

Co-Author: Youhyun Jang [1]

*[1] KHNP*

**Presentation Type: Poster**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 13: SMRs in Energy Planning for Climate Change Mitigation (D.13)

**INDICO Abstract ID: 296**

**Abstract**

As cities globally strive for sustainability, the concept of SMR Smart Net Zero City (SSNC) emerges as a pivotal solution. This paper explores the framework and strategies for establishing SSNC, focusing on leveraging Small Modular Reactor (SMR) as a foundational energy element. By integrating versatility of SMR with advanced technologies like IoT and AI, SSNC can achieve efficient energy management, demand response, and renewable energy integration. The paper discusses key components such as smart grids, energy storage systems, and intelligent energy management systems, emphasizing their role in optimizing energy consumption and reducing carbon emissions. Several virtual cities created based on actual energy production and consumption data simulate carbon reductions and energy costs to demonstrate the feasibility and benefits of SSNC implementation.

# Enabling factors for Small Modular Reactors (SMR) uptake in Bolivian future power system


**Speakers: C Mariani; M. Ricotti**

Primary Authors: Marco Herbas [1]; Stefano Lorenzi [2]; Chiara Mariani [2]; Nicolò Stevanato [2]; Marco Ricotti [2]

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**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 13: SMRs in Energy Planning for Climate Change Mitigation (D.13)

**INDICO Abstract ID: 385**


**Abstract**

To meet the global climate targets and decrease the consumption of fossil fuels, in addition to increasing renewable energy, a dispatchable low-carbon energy source is required. Nuclear power may represent a promising solution. The paper presents a study on the integration of Small Modular Reactors (SMRs) in the Bolivian power sector in 2035. The Calliope optimization tool is used to model and analyze different energy scenarios, considering parameters such as evolving energy demand, renewable resource availability, as well as technological and economic constraints for each energy technology. Two scenarios have been analyzed: a first one to assess the feasibility of introducing one or more SMR units into the Bolivian energy mix, and a second one where the competitiveness of nuclear power was tested, evaluating whether the introduction of new renewable sources would compromise the tool's choice to install SMRs. Results demonstrate that SMRs are integrated into the Bolivian energy mix, even in the case of an increased share of renewables. In addition, a sensitivity analysis revealed the economic thresholds beyond which nuclear energy is no longer economically advantageous. For example, with an interest rate of 11%, no SMRs are installed, while at lower interest rates or investment costs, the optimal solution involves the installation of at list one SMR unit.

# Italian Scenario: reintroduction of new nuclear and benefits for the system

**Speaker: G. Caprioli**

Primary Authors: Giada Caprioli; Lorenzo Mottura; Valeria Olivieri

**Presentation Type: Poster**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 13: SMRs in Energy Planning for Climate Change Mitigation (D.13)

**INDICO Abstract ID: 394**

**Abstract**

Challenging European and Italian regulation aims at reaching carbon neutrality in Italy by 2050. A scenario totally fueled by renewable sources would be compliant with this target, with strong drawbacks from economical and system security point of views. For this reason, through a proprietary model an optimized scenario has been drafted, starting from Italian PNIEC1 energy mix at 2030. Reintroducing nuclear technology2, with the first plant in 2030-35 and one plant per year, at 2050 a pipeline of 15-20 plants would cover the 10% of production. At 2050, ~20% of programmable capacity (nuclear and decarbonized gas) will guarantee economic and adequacy sustainability of the system. This optimized mix guarantees significant investment reduction (more than 400B€3). The introduction of new nuclear leads to positive impacts for the Italian system: - Macroeconomic: 40+ B€ GDP increase, 36+ k AWU4 during construction and 3+ k AWU in operation - Environmental: reduced LC emissions, land occupancy and water need - Strategic: revitalization of national industrial cluster, valorization of carbon neutral Made in Italy and boost of high-technology export in Europe (benefit enabled by the hybridization of electric and thermal applications) 1. Last version published in 2023, with import hp by Terna-Snam scenario (flat 50 TWh/y) 2. New nuclear technologies: SMR (commercially available after 2030) and AMR (after 2040) 3. Comparison vs 100% RES Scenario over the period 2030-2050, considering key cost items: electric storage, RES, grid and nuclear development 4. AWU: annual working units

# Nuclear-Renewable Hybrid Energy Systems: Considerations for Future Deployment in Ghana

**Speaker: E. Boafo**

Primary Author: Emmanuel Boafo [1]

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**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 13: SMRs in Energy Planning for Climate Change Mitigation (D.13)

**INDICO Abstract ID: 44**

**Abstract**

Nuclear and renewable energy offer the potential for significant long-term supplies of heat and power at relatively stable prices, and for producing lower GHG emissions than alternative fossil-fuel sources. Owing to their large capital costs and low fuel costs, nuclear power plants require a high load or capacity factor to be economically viable. Renewable energy sources on the other hand have the benefits of strong societal acceptance and the potential for smaller-scale, distributed installations. The integration of nuclear energy and renewable energy into a single nuclear-renewable hybrid energy system (NHES), using various coupling schemes, would enable a nuclear power plant to run at high capacity while also addressing the need for flexibility of generation rates and producing energy services, ancillary services, and low-carbon co-products. Small Modular Reactors (SMRs) are designed with safety as a top priority, incorporating advanced features and inherent safety mechanisms. These characteristics, coupled with their modular nature, make SMRs an attractive choice for newcomer countries such as Ghana. The opportunities in harnessing the benefits of both nuclear energy and renewable energy systems through the deployment of an integrated hybrid energy system are enormous. Despite the several benefits, however, several factors need to be considered before making an informed decision for the deployment of NHES. Some of these considerations include techno-economic analysis, regulatory aspects, stakeholder engagement, system interconnections as well as policy and governmental considerations. In this paper, these considerations will be discussed in detail and the

current needs analyzed in the Ghanaian context. Suggestions and recommendations that are expected to facilitate the deployment of NHES will also be discussed.

## Track 14: Nuclear Infrastructure and Enabling Environment for SMRs (D.14)

# Development of nuclear infrastructure based on different contracting models and risks assessment

**Speaker: Y. Chernyakhovskaya**

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**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 14: Nuclear Infrastructure and Enabling Environment for SMRs (D.14)

**INDICO Abstract ID: 41**

**Abstract**

The scope of activities and responsibilities division for nuclear infrastructure (NI) development is impacted by a chosen deployment model of a SMR project, which is reflected in the set of the contractual arrangements between the project parties. The range of common approaches in an embarking country encompasses a turn-key and a concession (build–own–operate). It is possible to determine the optimal legal construction for appropriate risks management based on parties' risk profile and ability to manage their risk. An insufficient NI is a framework for SMR budget overruns, schedule slippage, licencing challenges and safety. The determination of relevant obligations division in the project is possible based on the results of the (pre- ) feasibility study and NI assessment. To optimize NI for SMR projects in embarking countries, one of the backbone measures for NI development is assistance from the vendor state from the beginning, including a bilateral NI plan with fixed commitments of parties and cooperation between regulatory bodies on regulatory framework and safety assessment (pre-licensing).

# ANALYSIS OF SMRs IMPLEMENTATION IN ROMANIAN ENERGY SYSTEM


**Speaker: M. Constantin**

Primary Author: Marin Constantin [1]

*[1] RATEN ICN*


**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 14: Nuclear Infrastructure and Enabling Environment for SMRs (D.14)

**INDICO Abstract ID: 42**


**Abstract**

At the horizon of 2050, free carbon energy supply may be ensured mainly by the contribution of the renewables and nuclear plants. The deployment of SMRs contributes to create the desired security of supply, stability of system, and adaptation to the expected large penetration of intermittent renewables. However, despite the promising concepts and the diversity of the designs, the implementation of SMRs is facing several challenges leading, currently, to a modest level of implementation. A set of issues, such as economic uncertainty, financing challenges, competition with other energy alternatives, public perception, political context, regulatory hurdles, infrastructure requirements, and insufficient standardization are acting as barriers for the near-term deployment. The paper analysis the case of Romania with the peculiarities of the responses to these challenges. discussing the drivers determining the short-term implementation of iPWR SMR. A 6-modules plant is expected to be operational in 2030. On the other hand, the efforts for the development of advanced SMR are constantly supported by the national policies. Romania is the hosting country for ALFRED (LFR technology demonstrator and also a key step for the LFR-SMR development). An important progress is achieved by the on-going development of the experimental infrastructure for licensing. The analysis will be completed by including considerations on the regional context of the CEEC in terms of climate policies and energy strategic developments.

# Integration of Small Modular Reactors (SMRs) in Ghana's Energy Mix: A Pathway to Sustainable Development

**Speaker: J. Gbinu**

Primary Author: Joshua Gbinu [1]

Co-Authors: Felix Ameyaw [1]; Bejamin Emi-reynolds [1]; Mark Nyasapoh [1]

*[1] GHANA ATOMIC ENERGY COMMISSION*

**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 14: Nuclear Infrastructure and Enabling Environment for SMRs (D.14)

**INDICO Abstract ID: 62**

**Abstract**

ABSTRACT: The integration of Small Modular Reactors (SMRs) into Ghana's energy mix presents a promising pathway towards achieving sustainable development goals through the reduction of greenhouse gas emissions while addressing the challenges of meeting energy demand. This paper explores the key considerations and strategies for establishing an enabling environment to facilitate the successful deployment of SMRs in Ghana. Energy planning plays a pivotal role in aligning SMR deployment with national energy demand and climate goals. Through comprehensive energy planning, Ghana can optimize the integration of SMRs alongside renewables, ensuring a balanced and resilient energy system. Furthermore, the development of robust nuclear infrastructure, including capacity building and stakeholder engagement, is essential to build public trust and support for SMR projects. Again, financing and economic appraisals are critical aspects of SMR deployment, requiring innovative approaches to address investment challenges and to demonstrate the business case for viable deployment. The paper will explore various cost considerations, financing structures, and conditions that will support SMR projects in Ghana. Additionally, Reactor Technology Assessment (RTA) will be highlighted as a crucial component of SMR deployment, encompassing safety, reliability, and efficiency evaluations. This assessment will inform decision-making processes and ensure the selection of suitable SMR technologies for Ghana's specific energy needs and infrastructure. In conclusion, the paper advocates for a holistic approach to integrate SMRs into Ghana's energy mix, encompassing energy planning, nuclear infrastructure development, technology assessment, financing strategies, stakeholder engagement, and international cooperation. By addressing these critical issues, an enabling environment will be created for future deployment of SMRs in Ghana. Ghana can realize the full potential of nuclear energy to meet future energy needs and support sustainable development objectives. KEYWORDS: Small Modular Reactors (SMRs), Reactor Technology Assessment, Nuclear Infrastructure, Stakeholder Engagement, Financing structures.

# Small modular reactors and new technologies in the generation capacity expansion: The Brazilian perspective

**Speaker: G. C. Borges Leal**

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**Presentation Type: Poster**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 14: Nuclear Infrastructure and Enabling Environment for SMRs (D.14)

**INDICO Abstract ID: 65**

**Abstract**

The energy demand increase challenges operators to deal with multiple aspects, such as reliability, energy prices, power losses, and diversification of energy resources. In 2023, the Brazilian generation capacity rose 10,3 GW to achieve close to 200 GW of power generation under operation, and this behavior will continue. Currently under construction, Angra 3 nuclear power plant will be the third unit in the Almirante Álvaro Alberto power generation complex (CNAAA), all based on pressurized water reactors. This new plant will generate up to 12000GWh/year, attending approximately 60% of Rio de Janeiro's energy consumption and increasing the nuclear participation to 3% of the national energy matrix. Following this path, small modular reactors (SMRs) emerge as a potential new technology for new units in Brazil and a new opportunity for the national nuclear sector. This paper analyzes the principal aspects of SMRs, hydrogen, ocean energy, and other new power resources regarding the generation expansion studies for the Brazilian 2050 horizon. Furthermore, the study approaches the Uranium cycle and other issues regarding nuclear fuel that impact the Brazilian nuclear area.

# Assessing the Role of Small Modular Reactors (SMRs) in Achieving Sustainable Industrial Growth in Africa: Opportunities, Challenges, and Policy Implications

**Speaker: A. S. Aliyu**

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Co-Author: Umar Farouk Ahmad

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**Presentation Type: Poster**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 14: Nuclear Infrastructure and Enabling Environment for SMRs (D.14)

**INDICO Abstract ID: 73**

**Abstract**

Africa is regarded as a significant and rapidly expanding hub for factories and businesses, with a GDP of over 2.7 trillion USD, there is a growing need for clean and reliable energy to sustain its growth. This paper examines how Small Modular Reactors (SMRs) can be utilized to provide the necessary energy for Africa's factories and industries. SMRs are small, safe nuclear reactors that can generate substantial energy with minimal pollution. Africa's energy situation, including instances of insufficient energy and its detrimental effects on the environment, will be discussed. The advantages of SMRs, such as their ability to generate significant energy while producing minimal pollution, will also be addressed. Furthermore, the necessary measures to implement SMRs in Africa, including the establishment of regulations and waste management strategies, will be explored. By considering the utilization of SMRs in Africa, efforts can be made to ensure that the region's factories and businesses continue to grow in an environmentally friendly manner.

# Considerations for the More Viable Option in the Deployment of Traditional Nuclear Power Plants (NPPs) and/or Small Modular Reactors (SMRs) for the West African Sub-Region

**Speaker: E. Obande**

Primary Author: Patrick Akusu [1]

Co-Authors: Esa Obande [2]; Christiana Akusu [3]; Anthony Ekedegwa [2]

*[1] Air Force Institute of Technology; [2] Nigeria Atomic Energy Commission; [3] Nigerian Defense Academy*

**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 14: Nuclear Infrastructure and Enabling Environment for SMRs (D.14)

**INDICO Abstract ID: 90**

**Abstract**

The need for enhancement of the energy sector in Africa as well as the current global advocacy for carbon-neutral solutions to stem the adverse effects of climate change inspires the consideration of a number of energy-supply alternatives to fossil fuel. Nuclear energy has proven to be one of the most viable alternative energy solutions given its superior energy density and near-zero carbon footprint; moreover, a nuclear-driven energy sector serves as a fecund ground for the much needed technological advancement in the diverse industrial sectors of the West African sub-region. Recent advancement in the nuclear industry has resulted in the development of Small Modular Reactors (SMRs), which aim to deal with concerns about cost/financing, construction time, 3S, political and other factors as encountered with the traditional Nuclear Power Plants (NPPs). A critical analysis of the pros-and-cons for the deployment of SMRs as against NPPs in the sub-region is presented in terms of financing, 3S and prioritize local needs, technical expertise, political considerations amongst others. Though, SMRs remain a promising option that would sooth the current political atmosphere, traditional NPPs are still the more technically viable option for the much needed socio-economic development and affordable energy future of the sub-region.

# Plans for building organizational and human capacity under OSGE's nuclear power program


**Speaker: K. Kalend**

Primary Author: Katarzyna Kalend


**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 14: Nuclear Infrastructure and Enabling Environment for SMRs (D.14)

**INDICO Abstract ID: 96**


**Abstract**

Orlen Synthos Green Energy (OSGE) is a Polish company that plans to deploy a fleet of SMR reactors in Poland using the BWRX-300 technology provided by GE Hitachi Nuclear Energy (GEH). Poland has ambitions to decarbonize its energy mix using nuclear technology, both large-scale and SMR. Currently, Poland shortage highly qualified staff in the nuclear industry. Most Polish specialists gained experience abroad. To ensure the availability of qualified staff, there is a need to develop a training program which will be certified by our regulatory body in Poland. OSGE also plans to build a Training Center to provide potential candidates with the opportunity to acquire the skills, knowledge and experience necessary to safely operate future new nuclear power plants. OSGE works closely with OPG (Ontario Power Generation), which plans to build FOAK (the first of its kind), TVA from the USA and GE Hitachi (supplier of BWRX-300 technology) under TCA (Technology Collaboration Agreement) too. Thanks to this cooperation, we can benefit from the experience and conclusions of organizations with much longer experience in the nuclear industry.

# From Vision to Reality: Building Capacity and Bridging Gaps in SMR Technology Adoption

**Speaker: M. Ozerina**

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**Presentation Type: Poster**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 14: Nuclear Infrastructure and Enabling Environment for SMRs (D.14)

**INDICO Abstract ID: 98**

**Abstract**

This paper explores the transformative journey of Small Modular Reactors (SMRs) from conceptualization to practical implementation. It delves into the various aspects of SMR deployment, emphasizing the critical need for capacity building and collaboration to bridge existing gaps across multiple infrastructure issues specified in the IAEA publication NG-G-3.1 (Rev. 2) Milestones in the Development of a National Infrastructure for Nuclear Power. In the pursuit of sustainable and scalable nuclear energy solutions, nations are increasingly turning to SMRs. However, this transition involves overcoming several challenges, ranging from regulatory hurdles and technical complexities to developing human resources capable of managing SMR technology. The abstract examines strategies to turn the vision of SMR integration into a tangible reality. The discussion revolves around the collaborative efforts required for successful SMR deployment, emphasizing the importance of bilateral and multilateral engagements. Regulatory frameworks play a pivotal role, and the abstract explores how nations can cooperate to facilitate SMR reviews and deployment. It also sheds light on the significance of technical cooperation in ensuring the seamless integration of SMRs into diverse national infrastructures. Human resource development emerges as a key theme, addressing the skills gap and capacity challenges in deploying SMRs in international environments. The abstract outlines initiatives and approaches to enhance expertise and knowledge sharing among nations. Furthermore, the abstract highlights the crucial role of public engagement and stakeholder engagement in the developmental phase of SMRs. Effective communication and collaboration with diverse stakeholders are essential for building public trust and support, ultimately contributing to the success of SMR projects. In summary, this article comprehensively explores strategies,

collaborations, and initiatives required to build capacity and bridge gaps in the adoption of SMR technology on a global scale.

# Sustainability assessment of infrastructure for small modular reactor deployment in Vietnam using INPRO methodology

**Speaker: C. T. Tran**

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*[1] Vietnam Atomic Energy Institute*

**Presentation Type: Poster**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 14: Nuclear Infrastructure and Enabling Environment for SMRs (D.14)

**INDICO Abstract ID: 102**

**Abstract**

Small modular reactors (SMRs) are being considered as a potential solution that can help Vietnam reach decarbonization by 2050. However, most SMRs are still in the design or licensing stage, leading to challenges to assess their sustainability. According to the INPRO methodology, comprehensive sustainability assessment of SMRs is necessary, particularly if an embarking country plans to build and operate them for harnessing nuclear power. Among the assessment areas for SMRs, assessment of infrastructure is essential to ensure a country shall be able to deploy SMRs without excessively investing in national infrastructure. Thus, this work performed a limited scope assessment of infrastructure for SMR deployment in Vietnam using the INPRO methodology. It was based on the infrastructure previously established for the former nuclear power plant projects and aimed to pinpoint infrastructure issues which need to be solved to facilitate SMR deployment in Vietnam. National energy planning and policy was also taken into account to identify candidate SMR technologies which can be timely deployed for supporting the decarbonization target. The results could provide policy makers with initial recommendations on how to develop adequate infrastructure for future SMR introduction in Vietnam. Future works are being planned for the respective full scope assessment.

# Navigating the Energy Landscape: Considerations for Deploying Small Modular Reactors in Saudi Arabia

**Speaker: S. Alshehri**

Primary Author: Salman Alshehri [1]

Co-Authors: Anas Alwafi [2]; Salman Alzahrani [1]

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**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 14: Nuclear Infrastructure and Enabling Environment for SMRs (D.14)

**INDICO Abstract ID: 104**

**Abstract**

The article comprehensively focuses on various factors of Small Modular Reactor SMR deployment in Saudi Arabia as one of the strategic decisions that the country needs to make in its quest to have a sustainable and resilient energy future. The study explores the opportunities, that stem from building nuclear infrastructure, as many SMRs would be deployed. The article emphasizes how the elements of a favorable framework are considered, which demonstrates the significance of strategic planning and prudent allocation of financial resources in an endeavor to establish a stable foundation for the safe and efficient integration of SMRs. To what extent does Saudi Arabia has to harmonize its elevating energy requirements with a sustainability pledge, the article explores the particularities of the Kingdom's energy environment. This highlights the major SMR advantages and disadvantages in meeting the increased electricity demand and makes it clear how they may be used in concert with renewables at scale and adapt to different conditions quickly. Regulatory technicalities have a crucial role in dictating how fast it is adopted. This article provides ways of creating a rule of law that will be effective, of paying attention to international standards while keeping in mind local details and specific features. Economic viability is one of the aspects that are considered in the analysis, therefore, new financing mechanisms are to be looked into and potential ways of international collaboration are highlighted. The study analyses the long-term economic viability of SMRs in terms of operational costs, employment creation, and revenue streams, to ascertain their domesticated economic contribution to the Kingdom’s economic goals. This article attempts to provide a full-scale guide to the

policymakers, energy industry representatives, and the entire energy community in Saudi Arabia, as a means of better informed and logical decision-making to achieve a sustainable and diverse energy future.

# International Bank for Nuclear Infrastructure (IBNI) – A comprehensive and multi-dimensional solution to enable accelerated global scaling of SMRs

**Speaker: D. Dean**

Primary Author: Daniel Dean [1]

*[1] International Bank for Nuclear Infrastructure-Implementation Organisation Strategic Advisory Group*

**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 14: Nuclear Infrastructure and Enabling Environment for SMRs (D.14)

**INDICO Abstract ID: 106**

**Abstract**

[Article relates to Topic 4: Tracks 13, 14, 15, 16 & 17] The proposed multilateral nuclear infrastructure bank, IBNI[1] embodies a set of comprehensive solutions addressing unique multi-dimensional challenges impeding global scaling of nuclear technologies (including SMRs). This article will expressly address how IBNI will support SMR deployment within the specific context of 'Topic 4'. IBNI Standards & Criteria (S&C), together with IBNI funding and financing products, services and other support will promote 'best international practices', specifically related to: • Track 13: long-term decarbonisation policies and energy system planning supporting sustainable investments in low-carbon energy systems (including nuclear/SMRs); • Track 14: supporting IAEA MSs in accelerating nuclear infrastructure, human resource capacity development (and multinational resource pooling), institutions; • Track 15: optimal sets of revenue, financing, commercial/business, contractual, risk-allocation and project/program management models; • Track 16: diverse networks of political, industry and civil society stakeholder engagements in nuclear power project and programs; and, • Track 17: high degree of multinational alignment to a set of generally harmonised and standardised regulatory, energy and financial markets, ESG and business model frameworks. The article will further develop the unique value proposition of IBNI with respect enabling accelerated global scaling of SMRs and other nuclear technologies. [1] For additional details related to the proposed International Bank for Nuclear Infrastructure (IBNI), please see: www.nuclearbank-io-sag.org

# Jordan’s SMR RTA Experience

**Speaker: K. S. Hamdan**

Primary Author: Khaleel Hamdan [1]

*[1] Jordan Atomic Energy Commission*

**Presentation Type: Poster**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 14: Nuclear Infrastructure and Enabling Environment for SMRs (D.14)

**INDICO Abstract ID: 117**

**Abstract**

Jordan has been extensively studying using SMRs for electricity and water desalination. Being highly dependent on imported natural gas for its power, the need for a local cheap power source alternate is extreme. Since Jordan is a developing country, its abilities, and resources are limited, an evaluation matrix presenting these limitations was generated, in addition to the country's demands and needs to assess the compatibility of the design to the program’s needs. Several problems were faced due to the special treatment that SMRs demand forcing some modifications to the guidelines in the reference used No. NP-T-1.10 “Nuclear Reactor Technology Assessment for Near-Term Deployment”. Several technical proposals were challenged against it and a handful of reactors showed some promise. This paper discusses the steps and methods used in this evaluation and the result of this RTA as well as the challenges faced in the process such as migration from large reactors to SMRs.

# Challenges of SMR deployment in a Swedish setting

**Speaker: Å. Linné**

Primary Authors: Ase Waxell Linne; Nina Kivinen [1]; Maria Morgunova [1]; Marcus Lindahl [1]

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**Presentation Type: Poster**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 14: Nuclear Infrastructure and Enabling Environment for SMRs (D.14)

**INDICO Abstract ID: 145**

**Abstract**

Sweden is experiencing a new wave of interest in nuclear energy. This interest is largely driven by the recently changed pro-nuclear political landscape in the EU and Sweden, the emergence of new nuclear technologies and the estimated doubling of national electricity consumption. Drawing on an ongoing study of the reintroduction of nuclear technology in Sweden, this paper presents findings related to the main challenges perceived in the potential deployment of SMRs in Sweden. In a qualitative study connected to the ANItA (Academic-industrial Nuclear technology Initiative to Achieve a sustainable energy future) competence centre managed by Uppsala University, we investigate what the main nuclear actors perceive as the main challenges associated with the future deployment of SMRs in Sweden. The preliminary findings indicate that much of the challenges of deployment of SMRs are not related to technological challenges per se, instead, the main challenges are tightly connected to the organizational and regulatory context of embedding new technology; including lack of licensing regulations, lack of competences within nuclear, uncertainty of financing and cost estimates, as well as long-term political commitment.

# STATUS OF NATIONAL NUCLEAR ENERGY PROGRAMME IN MONGOLIA


**Speaker: C. Mavag**

Primary Author: Chadraabal Mavag [1]

*[1] Nuclear Energy Commission of Mongolia*


**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 14: Nuclear Infrastructure and Enabling Environment for SMRs (D.14)

**INDICO Abstract ID: 169**


**Abstract**

Mongolia has a lot of potential for renewable energy. Addressing national energy security, the Mongolia’s Long-term Development Policy, Vision-2050, aims to become self-sufficient in energy production and addresses nuclear energy topics. In order to support economic growth, effectively implement this policy, eliminating a pressure on its electricity system and to introduce a number of new energy sources such coal-fired and renewable energy sources to meet demands and expand the installed capacity is necessity. Currently, Mongolia importing about 20% electricity supply from neighbors and 80% of electricity comes from domestic energy sources, such as coal-about 80%, wind-10%, solar-5.8% and hydro-1.7% respectively. Since the country’s needs to transit its energy-mix into green energy-mix, the Government of Mongolia issued a joint order to establish a working group to study possibility of use of nuclear power in Mongolia. A working group determined, due to Mongolia's sparse population, vast landmass, and low energy consumption, the use of a SMR is a potential alternative to diversify energy sources and provide stable electricity which is reflected in the preliminary report, that covers necessary activities and studies to be executed includes but not limited to the establishment of NEPIO and preparation of pre-feasibility study. Preliminary report to be submitted to the Cabinet Office for the further decision on nuclear power programme.

# Norsk Kjernekraft and the advancement of nuclear in Norway

**Speaker: O. Aas-hansen**

Primary Author: Oyvind Aas-hansen [1]

Co-Authors: Steffen O. Saele [1]; Sunniva Rose [1]; Havard Kristiansen [1]; Natalia Amosova [1]; John Kickhofel [1]; Jonny Hesthammer [1]

*[1] Norsk Kjernekraft AS*

**Presentation Type: Poster**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 14: Nuclear Infrastructure and Enabling Environment for SMRs (D.14)

**INDICO Abstract ID: 241**

**Abstract**

Since establishing the company Norsk Kjernekraft ("Norwegian nuclear power") in summer 2022, the company has engaged with more than 45 interested municipalities and public support for nuclear energy nationally has risen to more than 50 %. The rising support stems from a huge need for clean energy to decarbonize existing industry, and a strong public opposition towards establishing large wind-parks in the pristine Norwegian nature. Although having never utilized nuclear energy, Norway has legislation and regulation related to nuclear power plant licensing, and the country has decades of experience with nuclear research reactors and associated R&D. In the present paper we will present the Norsk Kjernekraft approach in Norway, working largely bottom-up informing interested municipalities about nuclear and the possibilities with small modular reactors. We will also present our work so far, including our assessment of the IAEA milestones approach for Norway, and status of current initiatives for establishing SMR-NPPs at several sites across Norway.

# Possibilities for deployment of SMRs in Slovenia

**Speaker: T. Zivko**

Primary Author: Tomi Å½ivko [1]

Co-Author: Tomaz Nemec [1]

*[1] SNSA*

**Presentation Type: Poster**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 14: Nuclear Infrastructure and Enabling Environment for SMRs (D.14)

**INDICO Abstract ID: 312**

**Abstract**

Slovenia is a nuclear country with a NPP in operation since 1983 that in 2023 extended its operational lifetime for 20 years until 2043. A project for a new GEN III PWR is starting and according to plan it should begin its operation in 2037. In parallel, there are some other interesting options for investors in SMRs available in the country. In 2023, the Slovenian Ministry of the Environment, Climate and Energy started preparation of a joint project with US Department of State for assessment of possibility to replace coal-fired power plants with generation of electric energy by SMRs. The Ministry organized a task group of possible investors into SMR projects and national grid provider as well as regulator, the Slovenian Nuclear Safety Administration (SNSA) that will prepare the pre-feasibility study concerning possible deployment of SMRs in Slovenia. The task force will receive consultancy and technical help from prominent US energy services company. The role of the SNSA is to provide information on licensing processes and legislative requirements for SMRs, including assessment of site-specific characteristics such as external hazards and functional requirements for SMR design and operation. The Phoenix project is planned to be completed by mid-2025.

# ANALYSIS SUPPORT FOR ENHANCED NUCLEAR ENERGY SUSTAINABILITY: AN INPRO SERVICE TO MEMBER STATES

**Speaker: C. Johari**

Primary Author: Johanna Maria Christina Johari [1]

Co-Authors: Alexander Bychkov [2]; Galina Fesenko [2]; Sera Jeon [1]; Vladimir Kuznetsov [2]

*[1] IAEA; [2] Private*

**Presentation Type: Poster**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 14: Nuclear Infrastructure and Enabling Environment for SMRs (D.14)

**INDICO Abstract ID: 335**

**Abstract**

The IAEA's International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) supports Member States in their long-term strategic planning for deploying sustainable nuclear energy. Over the past decade, INPRO developed methods and scientific-technical analysis tools to support modelling and analysis of nuclear energy systems, including global and regional scenarios. These analysis tools are available to Member States and come in a service package called the "Analysis Support for Enhanced Nuclear Energy Sustainability" (ASENES). The Task "Global Scenarios," uses ASENES analyses to develop a global vision of sustainable nuclear energy in the current century and beyond. An ongoing collaborative project called ASENES-SMR, addresses sustainable deployment scenarios for small modular reactors (SMRs) in evolutionary scenarios. This project has 14 national and regional case studies, and the support of twelve Member States. The project identified some preliminary factors for successful deployment of SMRs: improving cost competitiveness and attractiveness for investment; introducing innovations in technology; and implementing institutional arrangements. For favourable economics, there needs to be a transition from economy of scale of reactors modules to the economy of mass production. These scenarios aids in the future planning and deployment of SMRs in strategic sustainable nuclear energy systems.

# Feasibility Study for Deployment of Future SMR in IAEA Member Country

**Speaker: J. Best, S. Pecko**

Primary Author: Joshua Best [1]

*[1] Sargent & Lundy LLC*

**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 14: Nuclear Infrastructure and Enabling Environment for SMRs (D.14)

**INDICO Abstract ID: 340**

**Abstract**

The abstract focuses on a feasibility study conducted in [reference county] where an evaluation of the suitability of various sites for hosting a small modular reactor (SMR) nuclear power plant (NPP) was conducted. The study assesses mature SMR technologies and provide insights into the next steps for deploying an SMR in [reference country]. The approach of the study is based on the guidelines established by the International Atomic Energy Agency (IAEA) in NG-T-3.3, NR-T-1.10, SSR-1, SSG-35, and SSG-79 and considers the priorities and needs identified by [country] stakeholders. The feasibility study is divided into two phases. Phase 1 involves a "red flags" study of the proposed sites to ensure their suitability for a new NPP. The outcome of Phase 1 confirms the suitability of multiple sites for hosting at least 1 market available SMR technology for further assessment. Phase 2 of the study characterizes the complex process of deploying an SMR in [country]. This phase includes a more detailed examination of the potential sites and an evaluation of various reactor technologies that best meets the needs of [country]. Various topics such as cogeneration, environmental, natural and manmade hazards, waste management, and water usage are also addressed in Phase 2. The feasibility study is a collaborative effort between [country] stakeholders and subject matter experts from Sargent & Lundy LLC. The study provides objective and defensible evaluations based on IAEA guidelines and reflect the priorities and values of [country] stakeholders.

# The Integration of Small Modular Reactors into a National Nuclear Power Programme - A SWOT Analysis of Nigeria INIR Mission

**Speaker: M. U. Onwuhaka [1]**

Primary Author: Uchenna Onwuhaka Madu [2]

Co-Authors: Chad Chinaemelu Anyaegbu [2]; Awwal Bisallah [2]

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**Presentation Type: Poster**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 14: Nuclear Infrastructure and Enabling Environment for SMRs (D.14)

**INDICO Abstract ID: 348**

**Abstract**

The International Atomic Energy Agency conducted an Integrated Nuclear Infrastructure Review (INIR) Mission for Nigeria in June 2015. The Member State requests an INIR mission. The INIR mission is conducted by a team of experts to peer review, using a transparent evaluation methodology, a member State's nuclear power infrastructure development status. The INIR mission evaluated the IAEA's 19 infrastructure elements needed to deploy large Nuclear Power Plants (NPP), which also applies to the SMR. Through the lens of strength, weaknesses, opportunity, and threat (SWOT), this paper examines the suitability of adopting the result 2015 INIR mission for application in SMR. The SWOT analysis shows that SMR integration into the Nigeria nuclear power programme is achievable with good planning and an effective implementation strategy.

# CANDU Owners Group: Excellence through Collaboration for an Evolving Nuclear Landscape

**Speaker: S. Iqbal**

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*[1] CANDU Owners Group*

**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 14: Nuclear Infrastructure and Enabling Environment for SMRs (D.14)

**INDICO Abstract ID: 374**

**Abstract**

The CANDU Owners Group (COG) has been supporting the Canadian Nuclear Industry over the last 40 years to achieve operational excellence and bring clean energy to the world. As the preeminent nuclear collaboration hub in Canada, COG is poised to support its members and the industry at large as the nuclear landscape evolves to meet national climate change goals and a shared vision of a sustainable and reliable power future. To that end, COG has established a SMR Program consisting of the Small and Medium Size Reactor Technology Forum (SMRTF) and the SMR Vendor Participant Program (SMR VPP). These groups drive a collaborative effort to accelerate the development and deployment of SMRs in Canada and worldwide, for both flexible on-grid and alternate applications. This presentation will provide an overview of the COG SMR Program with a focus on collaborative efforts with respect to fuel supply and security, radioactive waste, security, nuclear liability, regulatory topics and workforce development. The presentation will illustrate how the integrated and collaborative approach of the COG SMR Program brings advantages by de-risking plans for all partners and providing support to new entrants to the nuclear industry.

# Considerations on the Accelerated Deployment of SMRs

**Speaker: M. Ozerina**

Primary Author: Milana Ozerina

Co-Author: Jing Wang

**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 14: Nuclear Infrastructure and Enabling Environment for SMRs (D.14)

**INDICO Abstract ID: 415**

**Abstract**

The global efforts towards sustainable and resilient energy solutions have fueled interest in Small Modular Reactors (SMRs) as transformative elements in the nuclear energy landscape. This paper discusses the need for accelerating SMR deployment, emphasizing collaborative approaches involving stakeholders such as vendors, Owner/Operators, and governments. Key considerations include economic benefits, regulatory framework development, and collaborative initiatives to advance SMR technology. The International Atomic Energy Agency (IAEA) plays a crucial role in facilitating global collaboration on SMRs through two interconnected mechanisms: the Nuclear Harmonization and Standardization Initiative (NHSI) and the SMR Platform. All those elements are essential for realizing the full potential of SMRs in building a sustainable energy future. Recognizing the potential economic advantages, this paper highlights the need for a shortened timeline for the deployment of SMRs, especially in Phase 2 of the IAEA Milestone Approach, including early engagement of vendors in this process. The paper also describes incentives for vendors, Owner/Operators, and governments, including job creation, investments, expanding market presence, ensuring energy security, and carbon emission reduction goals. At the same time, the IAEA serves as a cornerstone in ensuring a harmonized, monitored, and well-educated landscape for SMR deployment. Hence, through strategic collaborations, early engagement, and regulatory streamlining, the trajectory toward global SMR deployment is illuminated and reinforced against potential impediments. As the world stands on the brink of a possible new nuclear renaissance, the joint effort from various stakeholders promises not only economic prosperity but also a resilient, low-carbon energy landscape. This shared vision of prosperity through the accelerated deployment of SMRs necessitates

concerted and continuous efforts to pave the way for a promising and sustainable future in nuclear energy.

# OPPORTUNITIES AND CHALLENGES IN INTRODUCING SMRS IN THE ECOWAS REGION

**Speaker: V. Nkong-njock**

Primary Author: Vincent Nkong-njock

**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 14: Nuclear Infrastructure and Enabling Environment for SMRs (D.14)

**INDICO Abstract ID: 416**

## Abstract

Energy continues to be a central constraint to the socio-economic development prospects of the ECOWAS region. The current level of development of the energy system is a bottleneck for the social, economic, and industrial development throughout the region. This paradoxical energy circumstance in the ECOWAS region has sparked interest in several Heads of States in the region who are keen to develop a common regional vision and plan on how to harness the different energy resources in the region so as to support their socio-economic development plans The paper is to take into consideration the electricity demand for the study that was developed and analyzed based on the expected/projected development of several influencing factors, showing the importance of nuclear power in the countries' energy mix. For the countries of the ECOWAS region with very limited grid, undertakings to build the infrastructure for a nuclear power programme will need to consider the implications and opportunities of sharing infrastructure building efforts that is very challenging. Remains therefore for countries that wish to build their own first nuclear power plant, the opportunity for building a SMR. The paper aims to prepare a reference framework for a number of studies that the ECOWAS States will need to have prepared, providing the technical framework for studies and associated actions related to the following seven principal infrastructure areas of consideration for the development of a nuclear power programme including (1) Comprehensive studies for developing a strategy for sustainable supplies of electricity, and the possible contribution of nuclear energy : Energy planning; (2) Nuclear and radiation safety infrastructure; (3) Legal framework; (4) Technological and industrial infrastructure; (5) Workforce planning for SMRs; (6) Fuel cycle back end and waste management policies and (7) 2 Nuclear power plant siting.

# Recent EU legislative proposals and the impact on SMR technologies deployment

**Speaker: G. Cardoso [1]**

Primary Author: Andrei Goicea [2]

*[1] TBC; [2] Nucleareurope*

**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 14: Nuclear Infrastructure and Enabling Environment for SMRs (D.14)

**INDICO Abstract ID: 435**

## Abstract

In recent years, the nuclear sector has started to regain visibility at EU level, mainly after the energy crisis but also due to the still ongoing geopolitical situation. In this context, nuclear in general and SMRs in particular have benefited from a series of enabling measures in recent legislative proposals such as the Sustainable Finance - Taxonomy and the Net Zero Industry Act. Likewise, the SMR deployment in the EU is now also supported by the European Industrial Alliance on SMR launched at the beginning of this year that aims at promoting the technology within future legislative proposals to be issued by the EU institutions. The paper will dive into the recent and potentially upcoming legislative proposals and the impact they will have on the SMR development as from the early 2030’s.

# WANO SERVICES TO SUPPORT SUCCESSFUL NEW NUCLEAR REACTOR DEPLOYMENT

**Speaker: H.j. Kim**

Primary Author: Hyo Jin Kim (world Association Of Nuclear Operators) [1]

*[1] World Association of Nuclear Operators (WANO)*

**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 14: Nuclear Infrastructure and Enabling Environment for SMRs (D.14)

**INDICO Abstract ID: 429**

**Abstract**

This paper is to introduce WANO services to support safe and successful deployment of new nuclear units of its member utilities. Since 2015, WANO and its members interacted to ensure safe and reliable deployment of various new nuclear power plants. Majority of new nuclear being large size, new technology reactors include the High Temperature Gas Cooled Reactor – Pebble Bed at Shidao Bay, the Floating reactors on Akademik Lomonosov, Beloyarsk Fast Breeder Reactors. WANO support has helped commissioning and safe startup of about 60 new reactors in the last 10 years. WANO, as a non-profit, member organisation of nuclear power plant operators in the world, is providing new units with customised supports according the technology, size, and experience of the new nuclear units. These services include multiple new unit assistance visits, operational readiness assistance, roadmap to operational readiness, and pre-startup peer reviews. Lessons learnt from new units started up in the last 10 years have proved that WANO services had been effective in supporting safe and reliable operations. The lessons learnt also highlighted that earlier engagement of new units with WANO activities is essential to build highest level of operational readiness.

# Some Technical and Institutional Issues to Accelerate Deployment of SMRs

**Speaker: V.usanov**

Primary Author: Vladimir Usanov [1]

Co-Author: Julia Kuzina [1]

*[1] Institute for Physics and Power Engineering*

**Presentation Type: Poster**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 15: Financing, Cost & Economic Appraisals and Contracting Approaches for SMR Projects (D.15)

**INDICO Abstract ID: 48**

**Abstract**

V. Troyanov, Iu. Kuzina , A. Gulevich, V. Usanov, A. Verbitsky JSC State Scientific Centre of the Russian Federation, Obninsk, Russia The vision on the development and deployment of SMRs is presented in the paper. The first SMRs were built in Russia in 1954 -1989. After this stage, SMRs of various types were designed but not built until early 2000s. New driving forces for the penetration of SMRs to the energy sector of the country are discussed in the paper. The recent accelerated development of the northeastern regions with rich natural resources but low population density and high cost of energy generation has created favorable conditions for the use of SMRs. However, it is necessary to revise the approaches used for construction of the reactors of large capacities and find new solutions to meet specific requirements of the remote regions. Comparison of the feasibility of these requirements for small PWRs of generation 3+ and generation IV reactors is provided. The discussion on the tasks of SMRs penetration is supplemented by consideration of their role as a large sustainable component of the future national and global energy sector.

# Innovative financing solution to scale nuclear investments - The international Bank for Nuclear Infrastructure

**Speaker: M. Kovachev**

Primary Author: Milko Kovachev (international Bank For Nuclear Infrastructure) [1]

Co-Authors: Fabienne Pehuet; David Stearns [2]; Elina Teplinsky [2]

*[1] International Bank for Nuclear Infrastructure ( IBNI); [2] IBNI*

**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 15: Financing, Cost & Economic Appraisals and Contracting Approaches for SMR Projects (D.15)

**INDICO Abstract ID: 49**

**Abstract**

The Conference of the Contracting Parties (COP28) to the UNFCC held in Dubai Nov-Dec 2023 has become the "Nuclear COP" as displayed in the media. The reason for that informal title was the unprecedented reference to nuclear in the Global Stocktake document known as "UAE consensus". More than 25 countries signed the Ministerial declaration setting the goal for tripling nuclear capacity by 2050 from the current 372 GW. The Nuclear industry as part of the Net Zero Nuclear initiative launched by WNA and ENEC, made Net Zero Nuclear Industry Pledge supported by more than 120 companies. Achieving these ambitious goals, requires adequate financing mechanisms for scaling nuclear investments. The lending policies of IFIs as the World Bank and other MDBs are lacking behind from the policies in support to all low carbon sources including nuclear. This alignment remains priority for scaling nuclear, however additional innovative financing mechanisms are critical for mobilizing the investments and supporting the nuclear market expansion through the development of enabling infrastructure in countries embarking on nuclear power. This importance has been recently underlined in the IEA Electricity 2024, report. This article provides case study based on the initiative to establish a multilateral international financing institution ("IFI"), named the International Bank for Nuclear Infrastructure (IBNI). The case study elaborates on the use of different financing tools foreseen in IBNI structure to demonstrate the SMR designs in the technology exporting countries as well as developing or adapting the nuclear infrastructure in technology importing countries and ensure the potential order book for

serial SMRs deployment. The article will further elaborate on the way the Special Operation Fund is designed to address the funding gaps in countries embarking or expanding nuclear power. In conclusion the study advocates for establishing IBNI as the way to improve nuclear competitiveness and achieving scale.

# Future Cost Projections of Small Modular Reactors: A Model-Based Analysis

**Speaker: J.k. Nøland**

Primary Author: Jonas Kristiansen Nøland (norwegian University Of Science And Technology) [1]

Co-Authors: Martin Nødland Hjelmeland [2]; Magnus Korpås [2]

*[1] Norwegian University of Science and Technology (NTNU); [2] Norwegian University of Science and Technology*

**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 15: Financing, Cost & Economic Appraisals and Contracting Approaches for SMR Projects (D.15)

**INDICO Abstract ID: 57**

**Abstract**

Forecasting the future costs of innovative energy technologies, such as small modular reactors (SMRs), presents a complex challenge due to a multitude of uncertainties and variables. With over 100 SMR designs currently competing globally for commercial viability, achieving cost-effectiveness is a critical hurdle, particularly given the smaller reactors' inherent lack of economies of scale. This paper presents a model-based approach for estimating the first-of-a-kind (FOAK) costs for SMRs across various sizes, alongside determining the necessary deployment scale to achieve the supplier's projected Nth-of-a-kind (NOAK) costs, considering expected learning curves. Our analysis reveals that while smaller SMRs initially face higher costs, they possess significant potential for cost reduction, primarily through enhanced modularization strategies. The study demonstrates that SMRs can competitively match or surpass the cost-efficiency of larger nuclear power plants and alternative energy sources, conditional on the strategic deployment of a sufficient number of units. This work contributes to a nuanced understanding of SMR cost dynamics and laying a foundation for future research on their economic integration into the power market.

# Cost-Benefit Analysis of Small Modular Reactor Deployment for Electricity Generation in West Kalimantan

**Speaker: S. Suparman**

Primary Author: Suparman Suparman [1]

*[1] National Research and Innovation Agency, Indonesia*

**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 15: Financing, Cost & Economic Appraisals and Contracting Approaches for SMR Projects (D.15)

**INDICO Abstract ID: 93**

**Abstract**

Small Modular Reactors (SMRs) are indeed gaining increasing attention due to their potential to be commercially available in the near future. The interest in SMRs has grown because of their lower investment requirements compared to large Nuclear Power Plants (NPPs). SMRs offer the promise of faster development and revenue generation, which could help offset their higher capital costs and provide a generation cost comparable to larger NPPs. However, the smaller size of SMR may lead to a loss of economy of scale, which could impact the generation costs of electricity. Therefore, conducting an economic cost-benefit analysis of an SMR program is essential for decision-makers. This analysis helps in evaluating and predicting the value of the project, determining its economic efficiency, and assessing its viability based on the net benefit it generates. The research aims to critically analyse the SMR program and conduct a Cost-Benefit Analysis (CBA) specifically focused on deployment program of SMR in West Kalimantan. The results indicate that the NPP project does not offer additional benefits over the Coal Power Plant (CPP) due to the high investment cost of SMRs. The analysis points out that if the investment cost for SMR is reduced by 10% (5,595 USD/kWe), SMR would have a higher Net Present Value (NPV) than CPP, indicating a more favourable financial outcome for the SMR project. Furthermore at a carbon tax rate of 20 USD/ton, the CPP would not be financially viable (negative Net Present Value), making the SMR a more attractive option under these conditions. At a discount rate of 5%, the NPV of SMR is higher than CPP. This information can be crucial for decision-makers when considering the economic viability of investing in SMRs as part of their energy strategy.

# Extended assessment of nuclear and alternative electricity generating technologies based on their impact on national GDP (Cost-to-GDP concept)

**Speaker: S. Rozhenko**

Primary Author: Sergey Rozhenko [1]

Co-Author: Vadim Karle

*[1] Kept*

**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 15: Financing, Cost & Economic Appraisals and Contracting Approaches for SMR Projects (D.15)

**INDICO Abstract ID: 122**

**Abstract**

The Leveraged Cost of Electricity (LCOE) metric is often used to compare production costs for initial planning to rank options and advocate solutions. The use of this metric may be very misleading as it doesn't tell about the affordability nor accounts for the impact on the national GDP for a particular country. To account for this complexity, we developed the new Cost-to-GDP extended cost assessment concept to estimate and compare costs of production for various power sources by joining LCOE and econometric methods within one parameter – called RealLCOE. The new method estimates cost share of imports within traditional LCOE comprising of imported fuel, equipment and services, adversely impacting GDP. The approach makes possible to choose the most affordable option by based not only the absolute LCOE value, but rather the actual cost to GDP for a particular generation technology depending for a country, which helps get the highest multiplicator for local economic development. Our research aims: • To describe the Cost-to-GDP concept; • To compare generating technologies using the cumulative effects on the national economy • To estimate impact of supply chain localization on RealLCOE for various generating technologies; • To illustrate specifics of SMR position at merit order ranking for developing countries Overall this helps to provide a more balanced approach toward nuclear and fossil technologies compared to renewables alternatives considering, especially important for early stage energy planning for developing markets considering SMR inclusion into energy mix.

# Controlling Investment Risks by Integrating Decommissioning by Design in SMR Development

**Speaker: A. Van Heek**

Primary Author: Aliki Van Heek [1]

*[1] Nuclear-21*

**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 15: Financing, Cost & Economic Appraisals and Contracting Approaches for SMR Projects (D.15)

**INDICO Abstract ID: 153**

**Abstract**

Nuclear-21 presents an innovative approach to Small Modular Reactor (SMR) development, emphasizing end-of-life considerations ('Decommissioning by Design') as not only a priority in the licensing and environmental assessment processes, but also in determining investment risks in new nuclear development. Our methodology prioritizes the meticulous planning of decommissioning sequences, aiming to minimize radiation exposure and radioactive waste, thereby easing the load on waste facilities and future generations. This holistic approach encompasses both physical design elements and organizational planning strategies, ensuring that end-of-life considerations are integral to licensing, environmental assessments, and investment decisions. We advocate for clear decommissioning frameworks from the outset, including funding mechanisms and responsibilities, to inform investment in both prototypes as well as the series plants. Leveraging 3D modeling and Building Information Modelling (BIM), we aim to significantly reduce decommissioning costs and associated investment risks. Our presentation will outline how these strategies can mitigate common decommissioning challenges. Examples of typical decommissioning issues which can be alleviated or even eliminated when considering decommissioning in the design process will be discussed.

# Economic Analysis of Thermal Energy Storage Integration in Small Modular Reactors Balance of Plant

**Speaker: F. Tassone**

Primary Authors: Giorgio Locatelli [1]; Stefano Lorenzi [1]; Marco Ricotti [1]; Federico Tassone [1]

*[1] Politecnico di Milano*

**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 15: Financing, Cost & Economic Appraisals and Contracting Approaches for SMR Projects (D.15)

**INDICO Abstract ID: 199**

**Abstract**

The increasing penetration of renewable energy sources in the electric grid intensifies more than ever the demand for adjustable power outputs. Nuclear plants often find load-following, though feasible, undesirable especially due to the associated thermo-mechanical stresses placed on reactor components. To help absorb the load variability and improve the overall plant economics we can integrate molten salt thermal energy storage (TES) into a Small Modular Reactor (SMR) balance-of-plant (BOP). This study assesses the economic viability of this approach through a discounted cash flow analysis. In particular, we are considering lead-cooled SMRs with an electrical capacity of about 100 MWe, 3 different TES tank sizes, and 6 BOP configurations for loading and unloading the molten salt at different rates. By storing excess thermal energy during low-demand periods and releasing it during peaks, it is possible to effectively meet fluctuating energy needs and improve overall revenues. We provide net present values and internal rates of return for the proposed systems by considering factors such as capital costs, operating expenses, revenue streams, and discount rates. The results show which configurations could be economically profitable, underlying the need to have such preliminary analysis to drive the design of nuclear systems adopting TES.

# EverGREEN 2045: An Energy Mix to Decarbonize Washington State

**Speaker: B. Tarufelli**

Primary Author: Brittany Tarufelli [1]

Co-Authors: Samrat Acharya [1]; Dhruv Bhatnagar [2]; Allison Campbell [1]; Kevin Harris [1]; Kaveri Mahapatra [1]; Patrick Maloney [1]; Bharat Vyakaranam [1]; Mark Weimar [1]; Ali Zbib [1]

*[1] Pacific Northwest National Laboratory; [2] Strategen Consulting, Inc.*

**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 15: Financing, Cost & Economic Appraisals and Contracting Approaches for SMR Projects (D.15)

**INDICO Abstract ID: 207**

**Abstract**

The Washington State Clean Energy Transformation Act (CETA) transitions the state to 100% clean energy by 2045. We examined the potential for flexible resources, including small modular reactors (SMRs), to replace existing fossil-fuel generation. We partnered with X-energy, developer of a Gen-IV High-Temperature Gas-cooled Reactor (HTGR) – the Xe-100, to gain access to proprietary cost data and develop realistic cost estimates. We designed future resource mix scenarios compliant with CETA and included deployments of SMRs and other flexible resources. We used power systems analysis tools (production cost modeling and transient stability analysis) to examine the cost and stability of the future resource mix. We investigated the economic feasibility of SMRs using the value of services earned. With our integrated economic and engineering modeling approach, we found that revenues earned are sufficient to cover variable O&M costs, but capacity payments or power purchase agreements will likely be necessary for SMRs to participate in the future resource mix. Other benefits from incorporating SMRs in the future resource mix included reduced carbon dioxide emissions, and in some scenarios, reduced congestion, and price volatility.

# Demystifying a Contract: Why Contract Price is not the Cost of the Project

**Speaker: I. Pletukhina**

Primary Author: Inna Pletukhina [1]

*[1] Hunton Andrews Kurth LLP*

**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 15: Financing, Cost & Economic Appraisals and Contracting Approaches for SMR Projects (D.15)

**INDICO Abstract ID: 222**

**Abstract**

Cost-overruns are one of the primary concerns for all the main stakeholders in the new nuclear projects: owners, contractors, and investors. Frequently, the projects are described in terms of the amounts, i.e., a “$20 billion contract”. However, referring to the “price of a contract” to describe the financial cost of a project is misleading. The price of a contract is likely a reflection of a certain budgetary ceiling estimated by an owner, a project price tag as hoped for by a contractor or some combination of both. That number is at best an approximation - and at worst wishful thinking - until the precise allocation of risks between an owner of a new nuclear project and a technology vendor/contractor has been worked out during contract negotiations. The presentation will provide a foundation of what is meant by “risk allocation” in a contract, identify a few examples of common contractual provisions that contain “hidden costs”, and explore the relationships between various provisions that have cost implications. The presentation will be useful for anyone that may be drafting, negotiating, and/or approving a contract for either a traditional nuclear power plant or advanced reactor project.

# From Design to Deployment: Project Management for Successful Completion

**Speaker: G. Borovas**

Primary Author: George Borovas [1]

*[1] Hunton Andrews Kurth*

**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 15: Financing, Cost & Economic Appraisals and Contracting Approaches for SMR Projects (D.15)

**INDICO Abstract ID: 223**

**Abstract**

Successful completion of a nuclear project, requires not only a competitive design, but a right project management strategy and its early prioritization. While it is natural for technology developers to prioritize research, development, and, perhaps, even testing of their design, accounting for certain “implementation” variables early in the process would lead to more realistic evaluation of both project financing and duration. From the decades building and operating nuclear power plants - and complex, expensive, and long-term projects in other industries - we can distill the “implementation” variables that should be incorporated into development of the overall project management strategy. The presentation will identify some of these variables from previous nuclear power projects, analyze how they may influence deployment of advanced reactor technologies, and suggest what technology vendors and customers/owners can do to minimize the risk that such variables may carry for the success of a project.

# Economic evaluation of SMR projects as an option to power plants burning hard coal in Czech Republic

**Speaker: P. Mach**

Primary Authors: Bretislav Horak; Petr Mach [1]; Lubor Zezula

*[1] UJV REZ*

**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 15: Financing, Cost & Economic Appraisals and Contracting Approaches for SMR Projects (D.15)

**INDICO Abstract ID: 256**

**Abstract**

This paper presents general observations from development of the technical-economic study of possibility to replace the existing heating plants and cogeneration power plants burning mostly hard coal exploited in local deep pit mines with a nuclear option located. The study specified nuclear option compiled from Nuclear Power Plants with Small Modular Reactors with capacity to reduce emissions from energy conversion sources for specific Region by approximately 80%. The Small Modular Reactors were sited in compliance of nuclear safety rules for siting of Nuclear Power Plants, connected to the Local District Heating Systems and the electric grids and located with consideration of the planned development of residence centers and industry. The economic assessment was carried out using the calculation of discounted cash flow for whole lifetime of the plants considered in the nuclear scenario. Uncertainties in the parameters used in the calculation were analyzed by sensitivity analysis to these parameters. Performed Calculations demonstrated that positive discounted cash flow results of nuclear option can be achieved with investment costs that correspond to credible construction price assumptions and to the operation costs derived from the operated nuclear power plants. The observations presented in the paper are focused on technical-economic elements of conceptual study of wide deployment of Small Modular Reactors aimed at decarbonizing the centralized heating plants. The final part of the study contains a list of items that require solutions during the development of the study or need to be solved with the permitting authorities.

# Steel-Concrete modular construction. Economic impact on the levelized cost of electricity in large reactors or SMRs

**Speaker: P.m. Alliard**

Primary Author: Pierre-marie Alliard [1]

*[1] NUWARD*

**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 15: Financing, Cost & Economic Appraisals and Contracting Approaches for SMR Projects (D.15)

**INDICO Abstract ID: 286**

**Abstract**

For nuclear power to remain an attractive option in the next decades, the cost of electricity must remain competitive with alternative sources, whereas investors and public acceptance have been eroded by new build projects costs overrun. Lots of reports have been published on means to stop the construction costs escalation that was observed for large reactors in the Western countries (OECD/NEA, IAEA). Regarding SMRs, the challenge to develop a viable business model is bigger, especially how to unlock cost reductions to compensate diseconomies of scale. Steel-Concrete Structures (SCS) is one of the possible economic drivers, by reduced Interests During Construction (IDC), indirect costs and owner's costs from the shorter schedule. However, outside generalities or technical evaluations, there is a lack of information on supplementary direct costs that may lessen the savings; moreover, the expected gain compared to reinforced concrete (RC) was not yet quantified in the literary in terms of reactor economic performance, namely the cost of electricity (LCOE) all included (capitalized cost, operation & maintenance, fuel, dismantling). From the feedback of the SCHEDULE RFCS EU funded project 800732 (full-scale ultimate safety building in SCS), we developed a simplified model to assess the construction method sensitivity in various scenarios. Savings depends finally on the size of the project as construction & commissioning schedules and costs breakdown are very different. For large reactors, SCS offers substantial LCOE discount ~0.92. The higher is the cost of money (WACC), the higher are savings. For SMRs, SCS is profitable in critical areas where it offers both schedule and direct costs reduction (e.g replacement of the pools steel liners). Elsewhere savings are generally smaller than for large reactors because civil works do

not represent the main part of the global schedule and costs. The “time to money” exchange rate is -0.4% LCOE per removed month.

# Facilitating SMR Deployment through Sustainable Project Financing: Perspective of a Developer

**Speaker: M. Shimofuji**

Primary Author: Mitsuo Shimofuji

**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 15: Financing, Cost & Economic Appraisals and Contracting Approaches for SMR Projects (D.15)

**INDICO Abstract ID: 311**

**Abstract**

Financing nuclear projects is one of the major impediments to SMR fleet deployment. There is much conversation about the role of governments in supporting financing of SMR projects. Many governments, including in the US and EU, have launched grants, tax credits, and other financing initiatives to facilitate at least initial demonstration projects of FOAK reactor technologies. While government support for successful nuclear projects has been essential, sustainable commercial fleet deployment of SMRs will require an innovative project financing approach to fund nuclear projects. Our proposed project finance model utilizes the best approaches common to the energy and mining commodity sector. We assert that the bankability of the Small Modular Reactor (SMR) sector and the widespread deployment of hundreds of SMR reactors hinges upon securing long-term offtake agreements with clear industrial end-users boasting strong balance sheets, as well as the availability of private funds and debt financing. Lenders may require guarantees from project proponent until commercial production begins. To mitigate this risk, project proponent must adhere to industry best practices for timely and cost-effective project delivery. Additionally, initial support from financial investors or, until a substantial number of SMRs are operational, governmental entities could facilitate the provision of guarantees to maintain the momentum of SMR deployment.

# Governmental and Multilateral Incentives for SMR Deployment

**Speaker: D.l.dua**

Primary Author: Douglas Dua [1]

Co-Authors: Colleen Grygier [1]; George Borovas [2]; Inna Pletukhina [1]

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**Presentation Type: Poster**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 15: Financing, Cost & Economic Appraisals and Contracting Approaches for SMR Projects (D.15)

**INDICO Abstract ID: 320**

**Abstract**

The nuclear industry has been described as being in a “stalemate”, because constituents facing first-mover concerns are trying to simultaneously generate orders for reactors, create a record of successfully deployed projects and build out a supply chain to sustain the industry’s scaling. Most participants agree that this triple-headed problem can only be resolved with various kinds and levels of governmental and other support. This paper will attempt to identify and explain the financial and other incentives which are necessary or desirable to set the table for SMR project deployment in various international markets. Covering existing and potential programs, the discussion will touch upon legal regimes and developments in the United States, Europe, MENA and Asia, and their interaction with contracting and financing approaches taken by project participants. Some of the specific materials to be considered will include tax incentives, loan guarantees, cost overrun insurance, utility asset-backed securitization, financial assistance, fuel banks and capacity markets and other price support.

# OPPORTUNITIES IN DEVELOPMENT BANKS' ENVIRONMENTAL AND SOCIAL SAFEGUARDS IN THE ACCEPTABILITY OF ADVANCED NUCLEAR REACTORS IN KENYA

**Speaker: D. Musyoka**

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Co-Author: Brian Nyawinda [2]

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**Presentation Type: Poster**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 15: Financing, Cost & Economic Appraisals and Contracting Approaches for SMR Projects (D.15)

**INDICO Abstract ID: 342**

**Abstract**

In Kenya, nuclear energy is poised to complement renewable sources, particularly through the adoption of small modular reactors. Long-term national energy plans outline incorporation of three units of nuclear power plants, each generating 291 megawatts, into the grid by 2038. Preliminary assessments for Kenya's inaugural nuclear power plant reveal a capital cost of approximately 500 billion Kenya shillings for a 300 megawatt plant. Financing hurdles such as high initial investment and public opposition, driven by concerns over safety and waste management are the major challenges for Kenya's first nuclear power plant. Following COP28, calls were made for development institutions like the World Bank to finance new nuclear energy projects. International Finance Institutions, including the World Bank, have a successful track record in financing capital-intensive energy projects like geothermal power generation in Kenya, this is attributed to robust environmental and social safeguards. Kenya's strategic environmental assessment for its nuclear program recommends adoption of international finance institutions' guidelines for environmental due diligence to complement the national environmental laws and regulations. Acquisition of financing from international finance institutions presents multiple opportunities for Kenya's nuclear power project: The financing challenge for the project will be met; leveraging the

international finance institutions such as World Bank's environmental and social standards presents an opportunity to garner local community and stakeholder acceptance of the nuclear project; and the national environmental and social framework will be enhanced. These opportunities will expedite the deployment of advanced nuclear power technology in Kenya

# Mitigating FOAK Risk in SMR Deployment: Insights from Contracting Approaches

**Speaker: R. Duncan**

Primary Authors: Ryan Duncan [1]; Phoebe Lind [1]

*[1] Last Energy, Inc.*

**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 15: Financing, Cost & Economic Appraisals and Contracting Approaches for SMR Projects (D.15)

**INDICO Abstract ID: 387**

**Abstract**

Small modular reactors (SMRs) offer a promising solution to the deployment challenges of gigawatt-scale nuclear projects, yet concerns over first-of-a-kind (FOAK) risk may deter potential customers. This paper proposes leveraging proven financing and contracting strategies from the renewable energy sector to alleviate FOAK anxiety among energy buyers. Through contracting strategies such as power purchase agreements (PPAs) and fixed price engineering, procurement, and construction (EPC) contracts, energy buyers only pay for the clean energy they receive, while developers can ensure cost predictability and performance accountability, thereby fostering customer confidence in the timely delivery of nuclear energy projects. Through a comprehensive analysis of the potential benefits and practical implications of these strategies, we contribute valuable insights on the deployment of FOAK nuclear reactors.

# National Reactor Innovation Center Advanced Construction Technology Program

**Speaker: L. Voss**

Primary Author: Luke Voss [1]

*[1] Idaho National Laboratory*

**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 15: Financing, Cost & Economic Appraisals and Contracting Approaches for SMR Projects (D.15)

**INDICO Abstract ID: 407**

**Abstract**

National Reactor Innovation Center Advanced Construction Technology Program Luke Voss Idaho National Laboratory, Idaho Falls, ID luke.voss@inl.gov Abstract. The National Reactor Innovation Center (NRIC) Advanced Construction Technology Initiative (ACTI) supports a transformation in nuclear energy construction and deployment costs as various nuclear energy economic studies have identified the major cause of cost overruns are due to civil construction and schedule risks. Enabling this transformation will increase the confidence of investors, energy system planners, policymakers, and ultimately consumers in the capability of nuclear energy to meet future needs. The initiative considers regulatory requirements for commercial nuclear implementation and will incorporate strategies to develop regulator experience in review of the technology. The advanced construction technologies explored have significant cost and productivity impacts on the design, permits, construction, and operation of a nuclear facility and NRIC seeks to further demonstrate these technologies. In 2021, NRIC awarded a cost-shared, multi-year project to GE-Hitachi Nuclear Energy (GEH) and other key stakeholders on the first ACTI project that aims to reduce the construction costs of building new reactors by more than 10% and significantly lower the scheduling risks and uncertainties associated with them. Included in this work are three key technologies – vertical shaft construction, fabricated steel/concrete modular wall systems, and monitoring and digital twins. Keywords: Advanced Construction Technology Initiative GE-Hitachi National Reactor Innovation Center

# Deployment of SMRs: a Risk-based Framework for “Public-Private Investment Partnerships 3.0”

**Speaker: A. Paterson**

Primary Authors: Cyril Draffin [1]; Andrew Paterson [2]

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**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 15: Financing, Cost & Economic Appraisals and Contracting Approaches for SMR Projects (D.15)

**INDICO Abstract ID: 425**

**Abstract**

Financing Advanced Reactors and SMRs must address not only economics, but the critical risks (e.g., reactor and fuel technical performance, regulatory uncertainties, and economics of construction, operations, and ultimately long-term disposal). Based on structured survey results, private industry lacks the full capability to address all risks, particularly regulatory uncertainties outside its control. The public sector (agencies, communities) must be actively involved in negotiating approaches that enable optimal financing for early build of advanced reactors – as was the case in the 1960s with the first commercial reactor construction. Responses to the critical risks require multiple mechanisms, under a banner of “Public-Private Partnership 3.0”, involving subsidies, regulatory reform and assistance (including testing), and negotiated risk-sharing and credit support between industry and government agencies. Subsidies and economics alone are not sufficient; regulatory reform and public investment are vital, and negotiation can lead most importantly to POSITIVE government budget results over the life of the financing. Keywords: Financing, Advanced reactors, Critical risks, Public-private partnerships, SMR

## Track 16: Public and Stakeholder Engagements in SMR Development and Deployment (D.16)

# Securing Small Modular Reactor Development in Remote Areas: Case Studies and Cultural Analysis in Indonesia


**Speaker: A. Meliana**

Primary Author: Alfitri Meliana [1]

*[1] National Research and Innovation Agency*


**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 16: Public and Stakeholder Engagements in SMR Development and Deployment (D.16)

**INDICO Abstract ID: 81**


**Abstract**

Indonesia is committed to achieving Net Zero Emissions by 2060, and one of its strategies involves the construction of a nuclear power plant (NPP). In collaboration with the United States, Indonesia plans to commence the construction of a 462 MW facility in 2023. This facility will utilize NuScale Small Modular Reactor (SMR) technology, representing a significant step towards advancing the clean energy transition in the country. Compared to conventional nuclear power plants, the construction of SMRs offers several advantages, notably in terms of flexible land requirements and a smaller footprint. Moreover, SMRs incorporate advanced safety features designed to withstand extreme weather conditions and various seismic events. Importantly, these reactors can be tailored to meet the specific needs of a country's power grid and scaled up as required. One of the primary objectives of deploying SMRs in Indonesia is to ensure widespread access to electricity across the nation. The initial phase of SMR development is planned for West Kalimantan, with the intention of expanding into other remote areas in the future. However, the implementation of SMR projects in remote regions necessitates thorough security assessments. This paper aims to analyze potential security threat scenarios associated with SMR development in remote areas of Indonesia. Through case studies and cultural analysis of Indonesian society, the study

seeks to assess the impact of local culture on nuclear security and identify strategies to mitigate potential risks.

# ENEN contribution to the development of SMR human resource

**Speaker: G. Pavel**

Primary Author: Gabriel Lazaro Pavel [1]

Co-Author: Kateryna Piliuhina [1]

*[1] European Nuclear Education Network*

**Presentation Type: Poster**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 16: Public and Stakeholder Engagements in SMR Development and Deployment (D.16)

**INDICO Abstract ID: 87**

**Abstract**

The European Nuclear Education Network – ENEN is an association of more than 90 representatives of higher education institutions, research organisations, technical support organisations and nuclear industry. In recent years the Small Modular Reactor – SMR technologies brought a new revival of the nuclear as environmentally friendly and clean energy source. The SMRs represented the innovation that new generations brought as a follow up of decades of safe utilization of well-known technologies used as large scale energy sources. Today, the SMR technology is perceived as a solution to replace other environmentally unfriendly technologies or as a solution to bring energy to remote locations. Also, small communities can benefit of clear energy from a clean source. In order to safely develop, build and exploit such technologies, qualified workforce is needed. Some of these EC funded projects like TANDEM ( fitting SMRs into hybrid energy systems) or ECC-SMART (joint EU-Canada-China related to SCWR-SMR) are trying to set the base for future SMR development. The European Small and Advanced Training Academy – ESTA, an initiative developed in 2023 by ENEN targets to correlate the education and training initiatives at EU level in order to avoid redundancy and increase efficiency in educational actions targeting SMR reactors.

# The value of early engagement between stakeholders to ensure successful deployment of SMRs in the Global South


**Speaker: I. Kirsten [1]**

Primary Author: Ingrid Kirsten [2]

Co-Author: Anthony Stott (vienna Center For Disarmament And Non-proliferation) [3]

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**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 16: Public and Stakeholder Engagements in SMR Development and Deployment (D.16)

**INDICO Abstract ID: 184**


**Abstract**

There has been limited engagement between developers and potential end-users of SMR technologies in the Global South. To ensure the successful deployment and sustainable operation of these technologies, early engagement between reactor vendors and end-users is essential. NGOs like the Vienna Center for Disarmament and Non-Proliferation (VCDNP) are well positioned to provide a platform for dialogue in an environment that enables frank and open discussion and facilitates better understanding of challenges and priorities. The VCDNP, in collaboration with the African Commission for Nuclear Energy (AFCONE) and other partners, is organising a three-day, multi-stakeholder workshop in South Africa from 30 April to 3 May 2024. The workshop will focus on challenges to deployment and to consider what can be done to better prepare African markets for SMRs. It will also provide an opportunity for international financial institutions, investment funds and philanthropic foundations to understand their critical role in the successful deployment of SMRs. Regulators and policymakers from African countries and international experts, including the IAEA, will participate. The VCDNP's paper will discuss the process and the outcome of this multi-stakeholder engagement, drawing lessons learned for future engagement with vendors, investors, policymakers and climate change and development assistance communities.

# STUDY OF KNOWLEDGE AND PUBLIC AWARENESS OF SMALL MODULAR REACTORS IN MALAYSIA

**Speaker: M. Idzat Bin Idris**

Primary Author: Mohd Idzat Bin Idris [1]

Co-Author: Muhammad Hannan Aziz [1]

*[1] Department of Applied Physics, Faculty Science and Technology, Universiti Kebangsaan Malaysia*

**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 16: Public and Stakeholder Engagements in SMR Development and Deployment (D.16)

**INDICO Abstract ID: 232**

**Abstract**

The application of nuclear energy is becoming more prevalent, especially to produce clean electricity. While conventional nuclear reactors offer large-scale power generation, their construction is time-consuming and expensive. Small modular reactors (SMRs), with capacities up to 300 megawatts (MW), present an alternative for providing energy in remote areas and aligning with the National Energy Policy's goals of efficient, economical, and low-carbon energy use. However, public acceptance is crucial for their feasibility in Malaysia. This study aimed to assess Malaysians' current perception of nuclear energy, measure their knowledge and awareness of SMRs, and explore the relationship between their perception of nuclear energy and their support for SMRs. A quantitative online survey was distributed nationwide, with 200 respondents participating. The results revealed a diverse demographic, with females constituting 56%, ages ranging from 14 to 74, and a majority holding bachelor's degrees. The findings indicated a mixed public perception. Despite concerns about safety and environmental impact, a general view exists of nuclear energy as a reliable source and a potential tool in the fight against climate change. However, knowledge of SMRs was relatively low, with nearly 58% of respondents demonstrating low levels according to the questionnaire. Nevertheless, overall awareness was moderate, with 54% expressing a good understanding of SMRs' potential for low-carbon energy production. While respondents exhibited positive support for SMR use in Malaysia despite security concerns, these

concerns did not significantly affect their overall support for their development. These results highlight the importance of strengthening public education through educational institutions and social media to enhance awareness and foster a more positive perception of SMRs in the context of Malaysia.

# Education through science: NNSTU master’s program «Nuclear power plants with SMR»

**Speaker: A. Dobrov**

Primary Author: Aleksandr Dobrov [1]

Co-Authors: Aleksandr Khrobostov [1]; Maksim Legchanov [1]

*[1] Nizhny Novgorod State Technical University*

**Presentation Type: Poster**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 16: Public and Stakeholder Engagements in SMR Development and Deployment (D.16)

**INDICO Abstract ID: 236**

**Abstract**

Since 2020, in cooperation with the Technical Academy of Rosatom, NNSTU (Nizny Novgorod, Russia) implemented a project to prepare the short-term courses and a full-fledged master's program «NPP with SMR» in English. The project consists of two parts. The first one - a program of train-the-trainer’s courses "NPPs with SMR: Main Aspects and Life-cycle" - a new educational product aimed at improving the qualifications of specialists from foreign partner countries in this field of engineering. The second - two-year master's program, whose graduates are preparing for research, design and development activities in the field of nuclear engineering of NPPs with SMR. The main topics of study of the Master's degree program are focused on innovative approaches in the design and construction of nuclear power plants, SMR safety assurance, hydrodynamics and heat transfer, methods for solving engineering problems of SMR, Rosatom production system in the design and construction of power plants. In addition to lectures, there are a large number of practical classes in laboratories. NNSTU has several unique research test facilities that simulate thermal-hydraulic processes in different type small modular reactors. Aerodynamic facility FT-50 for modeling the coolant hydrodynamics in the core of the RITM-200 and KLT-40S reactors; multifunctional facility FT-40 for studying mixing processes in the water-cooled SMR pressure vessel; high-pressure stand FT-A1 for studying processes in HTGR; FT-4 test facility with lead coolant for modeling processes in the equipment of the SVBR and BREST reactors. The report will provide information about the structure of the

educational process, about the experimental facilities of NNSTU and information about scientific researches conducted by students studying through this program.

# Systematic Literature Review on the Risks of SMRs

**Speaker: B. Kocsis [1]**

Primary Author: Balazs Kocsis [2]

*[1] TBC; [2] MVM Paks NPP Ltd.*

**Presentation Type: Poster**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 16: Public and Stakeholder Engagements in SMR Development and Deployment (D.16)

**INDICO Abstract ID: 313**

**Abstract**

There is a lot of research on SMRs, from technological developments to their environmental impact. The aim of this presentation is to identify and synthesise, in a systematic review, relevant literature from key international sources from around the world, from the last 10 years (2013-2024). My research focuses on the dangers associated with small modular nuclear power plants. In addition to the undoubted advantages, there is therefore the social issue of the economic viability, the potential for nuclear accidents and the management of the waste generated by their operation.

# Initiatives in INPRO for SMRs

**Speaker: N. Das**

Primary Authors: Carolynn Scherer [1]; Nilormi Das [2]; Sera Jeon [2]; Gaye Sayin [2]

*[1] IAEA - INPRO; [2] IAEA-INPRO*

**Presentation Type: Poster**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 16: Public and Stakeholder Engagements in SMR Development and Deployment (D.16)

**INDICO Abstract ID: 389**

## Abstract

The concept of sustainable nuclear energy development through strategic energy planning is facilitated by the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO), a key programme of the International Atomic Energy Agency (IAEA). The INPRO programme has various activities supporting Member States (MSs) in strategic planning for sustainable nuclear energy incorporating small modular reactors (SMRs). INPRO brings together technology developers and users in capacity building. INPRO's collaborative SMR projects, aim to formulate prospective scenarios and success factors for sustainable nuclear energy systems deployment with SMRs, including potential cooperation models. Additionally, INPRO supports MSs through its nuclear energy system assessment (NESA) utilizing the holistic INPRO methodology, which encompasses six key areas for sustainability: economics, safety, infrastructure, environmental impacts, proliferation resistance, and waste management. INPRO is working with several MSs in performing NESA's for SMRs. Another project is the INPRO Dialogue Forums (DF), which provides a platform for technology holders and users to exchange knowledge on sustainable nuclear energy development and deployment; specifically, the 21st and 22nd DFs addressed SMRs. The INPRO methodology assesses nuclear energy systems to identify gaps in sustainability during design phases and promotes advancing sustainable SMR deployment.

# Systematic Review on Public Perception and Acceptance of Small Modular Reactors: Challenges and Strategies

**Speaker: B. R. Carvalho**

Primary Authors: Delvonei Alves De Andrade [1]; Elaine Rodrigues [2]; Beatriz Rodrigues De Carvalho [3]

*[1] IPEN; [2] IPEN-CNEN; [3] UNB*

**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 16: Public and Stakeholder Engagements in SMR Development and Deployment (D.16)

**INDICO Abstract ID: 408**

**Abstract**

Small Modular Reactors (SMRs) have emerged as a promising alternative for decarbonization, with significant advantages in terms of flexibility, safety and cost. Their success depends on technical feasibility, an adequate regulatory framework and public acceptance. Based on a comprehensive systematic literature review, the aim of this study is to analyze public perception and acceptance of Small Modular Reactors. For its development, the PRISMA methodology (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) was used in the scientific databases Scopus and Web of Science, using descriptors related to the subject under investigation. The results were synthesized systematically, identifying patterns, trends and gaps in the literature related to public perception and acceptance of SMRs. The main concerns raised by the studies were highlighted, as were the factors that positively or negatively influence the acceptance of these technologies, as well as the implications of the evidence for public policy, regulation and the practice of the nuclear industry.

# Adding resilience features in new reactor designs to adequately fulfil nuclear safety principles: Insights from small modular reactors

**Speaker: J.n. Widyamanto**

Primary Author: Johanes Widyatmanto [1]

Co-Author: Rafaela Hillerbrand [1]

*[1] Karlsruhe Institute of Technology*

**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 16: Public and Stakeholder Engagements in SMR Development and Deployment (D.16)

**INDICO Abstract ID: 364**

**Abstract**

Given the importance of safety principles from both nuclear energy ethics[1] and the IAEA[2], how could we ensure that new reactor designs, particularly Small Modular Reactors (SMRs), adequately fulfil these principles? Among existing SMR designs, the ARIS (Advanced Reactors Information System) database notes that NuScale, an American SMR company with approved designs by the US Nuclear Regulatory Commission[3][4] distinguishes resilience features[5] from safety features[6]. This distinction could provide insights on adequate fulfilment of safety principles. This is a contribution from nuclear energy ethics to nuclear energy policymaking. By highlighting resilience features, we argue that new reactor designs can adequately fulfil safety principles when resilience features are added to safety features. We do this by 1) showing that the addition of resilience features as exemplified by NuScale's SMR designs enhances nuclear safety; 2) explaining how adding distinct resilience features on top of safety features ensures the fulfilment of IAEA's safety principles, particularly responsibility for safety (principle 1), prevention of accidents (principle 8), emergency preparedness and response (principle 9), and reducing unregulated radiation risks (principle 10). Finally, we 3) propose how readiness towards the unanticipated as the core of resilience features are applicable to regulations for new reactor designs. Keywords: Small Modular Reactor (SMR), safety features, resilience features, safety principles, nuclear energy ethics. 1. Taebi B, Roeser S, eds. The Ethics of Nuclear Energy:

Risk, Justice, and Democracy in the Post-Fukushima Era. Cambridge University Press; 2015. doi:10.1017/CBO9781107294905 2. Fundamental Safety Principles. INTERNATIONAL ATOMIC ENERGY AGENCY; 2006. https://www.iaea.org/publications/7592/fundamental-safety-principles 3. ARIS - Home. Accessed December 26, 2023. https://aris.iaea.org/ 4. About Us | NuScale Power. Published 2024. Accessed March 14, 2024. https://nuscale-prod-7ri9iy8kt-nuscale-power.vercel.app/about 5. Palmer C, Baker G, Gilbert J. NuScale Plant Resiliency to an Electromagnetic Pulse. Trans Am Nucl Soc. 2018;119. 6. VOYGR SMR Plants | NuScale Power. Published 2024. Accessed March 14, 2024. https://nuscale-prod-7ri9iy8kt-nuscale-power.vercel.app/products/voygr-smr-plants

# Minilaterals for Small Modular Reactors: Cost Effective and Environmentally Sound Energy Transition Towards Global Net Zero

**Speaker: H. Desai**

Primary Author: Hely Desai [1]

*[1] University of Cambridge*

**Presentation Type: Poster**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 17: Cooperation for Harmonization and Standardization (D.17)

**INDICO Abstract ID: 266**

**Abstract**

Small Modular Reactors (SMRs) endorsed as the au courant solution to the dire global energy crisis are still in the incipient stage of its designing and deployment. While developing countries like India have had SMRs on their policy line-ups for a couple of years now, they haven't translated to practical commercial options given the lack of a standardized design, augmented investments and delayed profits, and major security concerns. Minilateral partnerships with like-minded countries to homogenize SMR design structures, regulation and safety approaches, with a shared goal of meeting energy demands and achieving climate goals, will aid in facilitating a conducive environment for SMR deployment by improving capacity-building, proposing shared investment models, and subsequent global design standardization. This paper will make a case for the importance of a 'minilateral approach' towards the deployment of SMRs for developing and poor economies with collaborative endeavours, shared economic burden and reduced financial risks, tech-support from their developed allies to reach a green and sustainable future. SMRs will be key in increasing the nuclear energy share into the global energy grid. This paper analyzing such the advent of minilateral alliances that will focus on green taxonomies and the incorporation of SMRs into the developing countries' energy agenda, will also shed light on the need for an extensively elaborate technology-neutral policy framework and international harmonization on achieving net-

zero. Further, for an India-specific case study from a policy perspective; inviting foreign and private sector investments into its currently only government-run nuclear energy sector, will prove to make India and asset to such collaborative partnerships.

# NUWARD Joint Early Review: a pragmatic approach to development of an internationally licensable standardized SMR design

**Speaker: K. Deknopper**

Primary Author: Karel Deknopper [1]

Co-Author: Julien Drure [1]

*[1] NUWARD EDF*

**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 17: Cooperation for Harmonization and Standardization (D.17)

**INDICO Abstract ID: 289**

**Abstract**

In the context of global decarbonization, nuclear energy and more specifically SMRs present a significant potential. The NUWARD SMR is being developed to meet the European and wider international market energy needs. From the early design phases, development of a modularized and simplified standardized design has been targeted, to be deployed internationally without significant re-design. In a global context where nuclear regulatory frameworks can present differences between countries, a pragmatic approach, called 'Joined Early Review' (JER), has been developed. While the (pre-)licensing process is ongoing in France, where the first NUWARD SMR is expected to be built, it was agreed to extend the licensing preparation to other European Regulators through this JER initiative. The first phase of the JER was performed by French, Finnish and Czech Regulators, running in parallel with the conceptual design phase. The second phase started in parallel with the basic design phase and is performed by the same group of Regulators extended with Swedish, Polish and Dutch Regulators. This paper explains the JER initiative, its objectives, topical approach, and working methodology. The experience feedback from the first phase will be addressed, as well as its incorporation in the ongoing design. Finally, the importance of the JER initiative within the global context of international harmonization initiatives will be discussed.

# United States and Canada Cooperation on SMR Design Reviews - Successes in Collaboration

**Speakers: S. Eaton; G. Bowman**

Primary Authors: Sarah Eaton [1]; Matthew Naraine [1]; Mohamed Shams [2]; Donna Williams [3]

*[1] Canadian Nuclear Safety Commission; [2] U.S. Nuclear Regulatory Commission; [3] US Nuclear Regulatory Commission*

**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 17: Cooperation for Harmonization and Standardization (D.17)

**INDICO Abstract ID: 303**

**Abstract**

Since 2019, the U.S. Nuclear Regulatory Commission (USNRC) and the Canadian Nuclear Safety Commission (CNSC) have been collaboratively performing safety reviews of advanced reactor and small modular reactor designs that are expected to be deployed in both countries. This collaborative effort aims to gain efficiencies by making joint observations or identifying and addressing where differing regulations regulatory approaches may result in different outcomes. CNSC and USNRC leverage each other's regulatory reviews and make joint findings that can support licensing in both countries. The effort focuses on strategic technical areas, both generic and design specific. Since initiation, both regulators issued 9 work plans for collaborative projects, collaborated on 5 reactor designs, and issued 8 joint reports. In response to lessons learned, we established processes to enable more efficient execution and optimize results including identifying criteria to strategically select licensing projects, creating a strategic plan to prioritize next projects, developing criteria to determine when additional regulators should be invited to join, and developing administrative protocols and templates for preparation, approval, legal review, and publication of joint reports. The feedback from reactor designers has been positive noting that the engagements are constructive, and that gaps are being identified early. The collaborative effort is returning value for regulators and designers in the form of complex technical issue resolved, and resources saved.

# Collaboration – the key to standardized SMR deployment

**Speaker: R. Tanguy**

Primary Author: Ronan Tanguy [1]

Co-Author: Allan Carson [1]

*[1] World Nuclear Association*

**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 17: Cooperation for Harmonization and Standardization (D.17)

**INDICO Abstract ID: 326**

**Abstract**

The successful worldwide deployment of SMRs is fundamentally dependent on developers' ability to construct plants with factory produced modules that are as identical as possible. Differences in approaches to national nuclear regulation however currently demand significant changes to NPP designs when a reactor is exported. These national approaches to regulation effectively reset projects outside the reactors' country of origin to first of a kind (FOAK) deployments. This is not only a regulatory challenge and the presentation will also explore the role of industry in developing and utilizing relevant good practice to support deployment of standardized designs To learn the lessons from previous licensing, construction, and operation experience and support Nth of a kind (NOAK) deployment of SMRs it is critical that greater collaboration between stakeholders is facilitated as soon as possible. The nuclear industry and governments came together during COP28 to sign pledges in support of tripling nuclear capacity by 2050. This will require the deployment of 40GWe nuclear capacity every year for the next 25 years, equivalent to a yearly addition of 70 SMRs and 20 GW NPPs. The recently released joint industry association framework report outlines a 3-phase approach moving towards towards greater efficiency and collaboration in regulatory reviews, which is a critical component to support the scale of deployment necessary. Such a framework requires a shift in mindset and approaches but there are many steps along this journey and changes will not be overnight. The initial proposal would be to start small and develop the process and bounding criteria for a small number of diverse regulators on specific designs.

# Nuclear business: shifting from supply chain to ecosystem configuration

**Speaker: V. Skliarenko**

Primary Author: Valeriia Skliarenko [1]

Co-Author: Giorgio Locatelli [2]

*[1] Politechnico di Milano; [2] Politecnico di Milano*

**Presentation Type: Poster**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 17: Cooperation for Harmonization and Standardization (D.17)

**INDICO Abstract ID: 338**

**Abstract**

According to (NEA, 2022) the potential market for small modular reactors (SMR) is 375 GW of installed capacity by 2050. However, the current supply chain configuration, characterized by short-term contracts and limited suppliers, is a major constraint for this vision, since on inside acts as a bottleneck and, on the other side, increases transaction costs for the stakeholders e.g. vendors, suppliers, and utilities. The linear "supply-buy" relations in the nuclear industry do not allow the flexibility and scalability required for the large scale SMR deployment. Achieving such a large-scale deployment requires a shift in the nuclear business from the traditional "supply chain" to a more flexible "ecosystem" mindset and business model. The nuclear sector needs to reach a balance between the nature of the business (e.g. the quality and regulation in components provision) and the openness of ecosystem business model. A key strategy would be to shift the perspective from “one-off projects” procured in a supply chain approach to a “program” (ideally across countries and design) leveraging an ecosystem business model. Establishing this ecosystem, particularly in the value-added segments of the business, has already proved to be successful in other sector, such as the aircraft industry. Therefore, the question is NOT if the nuclear industry should follow a similar path, but HOW can it establish an ecosystem? NEA (2022), Meeting Climate Change Targets: The Role of Nuclear Energy, OECD Publishing, Paris

# Redefining international dialog: Invent innovative frameworks for licensing Small Modular Reactors

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**Presentation Type: Oral**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 17: Cooperation for Harmonization and Standardization (D.17)

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**Abstract**

Beyond the sustained efforts of the international nuclear community to promote common safety principles and approaches, nuclear safety regulatory frameworks remain very national specific at the implementation level. While many SMR designs are being considered across borders, with the industrial imperative of minimizing design changes, convergences of regulatory standpoint emerge as crucial. Sharing regulatory views and practices is a first step to streamline regulatory processes, to facilitate efficient licensing procedures across jurisdictions and at the same time to promote the highest safety level reasonably achievable. Through the Joint Early Review (JER), six European regulatory bodies are conducting a synchronised preliminary review of the Nuward SMR, focused on a selection of key topics. This initiative enables the vendor to refine its design in a very early phase but it also raises regulators readiness by considering different regulatory approaches. Maturity of documentation, involvement of the vendor and commitment of regulators have been key conditions for a successful collaboration. The early outcomes of the JER highlight the benefits of such initiatives. It also confirms the need to develop new frameworks to address the challenge of licensing a very large diversity of designs, supported by new applicants, while ensuring the highest standards of safety.

# THE EUR ASSOCIATION – REVISION F OF THE EUR DOCUMENT AND ONGOING WORK ON SMR REQUIREMENTS

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**Presentation Type: Poster**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 17: Cooperation for Harmonization and Standardization (D.17)

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**Abstract**

Since 1991, the European Utility Requirements (EUR) Association has been developing and promoting harmonized technical specifications for the new mid- and large-size LWR designs to be proposed by the vendors in Europe. In 2024, it is composed of 13 companies involved in new nuclear projects or in electricity generation from nuclear power in Europe. One objective of the Association is to keep strong interactions with important stakeholders in the nuclear industry and regulation in Europe and worldwide, mainly: IAEA, WENRA, ENISS, WNA/CORDEL, European Commission (EC). The EUR Association issues and, from time-to-time, modifies and updates a report entitled "EUR Document". It consists of a comprehensive set of requirements covering the whole Nuclear Power Plant (NPP). It encompasses all aspects (safety, performance, competitiveness) and all parts of a NPP (Nuclear Island and Conventional Island). The paper describes the main results obtained in the following fields: 1. The last applicable revision, Revision E, of the EUR Document was issued in December 2016. It includes: Revised safety requirements taking into account the most recent European and international safety standards issued by WENRA and IAEA; The lessons learned from the Fukushima accident; and the most recent international standards, for example for I&C. The Revision E of the EUR Document has been benchmarked by the EC against recent safety standards. 2. The assessment of new designs. The Russian AEP's VVER TOI and Chinese CGN's EU HPR1000 designs have been assessed recently. One new design assessment is in progress (Korean KHNP's APR1000 namely). The presentation briefly recalls the EUR design assessment objectives and process and the progress of the different assessment projects. 3. The evolution of the EUR document towards integration of Small Modular Light Water Reactors (SMLWR). The paper presents the

dedicated report issued by the EUR Association about high level requirements for SMLWR design.

# SHAPING MSR STANDARDIZATION FOR EUROPE'S ENERGY FUTURE THROUGH SCIENCE

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**Presentation Type: Poster**

**Group:** Topical Group D: Considerations to Facilitate Deployment of SMRs

**Track:** Track 17: Cooperation for Harmonization and Standardization (D.17)

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**Abstract**

The Joint Research Centre (JRC), as the European Commission's science and knowledge service, plays a pivotal role in integrating scientific research with practical regulation through the Putting Science Into Standards (PSIS) initiative. In partnership with CEN-CENELEC, the JRC leverages its pre-normative research capabilities to forecast and address the standardization needs of emerging technologies. The 2024 PSIS workshop, focused on Molten Salt Reactor (MSR) technologies, exemplifies this foresight approach, uniting stakeholders across research, industry, policy-making, and standardization to align on the path forward for MSR standardization. The paper, arising from the PSIS workshop, details the collaborative effort to identify and prioritize standardization areas crucial for the safe, secure, and efficient deployment of MSRs, a technology increasingly recognized for its potential in contributing to the EU's energy transition and climate goals. It underscores the urgency for harmonized safety assessments, validated data on thermo-physical properties, fuel qualification processes, and material and component standards, all of which are instrumental in enabling MSR innovation. The workshop's outcomes signal a collective commitment to developing a comprehensive standardization roadmap, aiming to catalyze MSR deployment in alignment with the Net Zero Industry Act and to reinforce Europe's leadership in clean and sustainable energy technologies.