Call for Research Proposals for Participation in the New Coordinated Research Project (CRP) Sponsored by the International Atomic Energy Agency (IAEA)

Technical Evaluation and Optimization of Nuclear-Renewable Hybrid Energy Systems

<<CRP I32012>>

Summary of the CRP

Nuclear and renewables are the two principal options for low emission energy generation. However, synergies among these resources have yet to be fully exploited, and advantages of directly integrating these generation options are only now being explored for both the grid and to provide energy for other commodity products. Coal, natural gas, nuclear power plants and hydro stations are generally considered dispatchable sources of energy generation; meaning they can adjust to changing electricity demand. In contrast, some renewable energy sources such as wind and solar are variable due to their dependence on the weather and time of day. Analysis, leading to the optimized integration of the low emission generation options is necessary to transition to sustainable energy systems. Nuclear - renewable hybrid energy systems (HES) consider opportunities to couple these resources to leverage the benefits of each technology and their mode of operation on the system to provide reliable, sustainable, and affordable electricity to the grid and to provide low emission energy to other energy use sectors. This CRP therefore aims to advance technical development for coordinated use of these system that may be used to evaluate the potential benefits of nuclear – renewable HES in support of future sustainable energy systems, especially with reduced environmental impacts. Nuclear technologies may include water cooled or advanced, water and non water cooled reactor technologies and the application of those technologies for a range of energy needs. Renewable options may include, but are not limited to, electricity generation via wind, solar, hydro, water, and geothermal; direct use of heat from concentrating solar or geothermal; and other renewable energy commodities (e.g., biomass). Energy storage is often linked to or integrated within these examples. The key energy system figures-of-merit will be defined, and the review analysis methodologies and available data to assess the technical potential for using nuclear energy, alongside renewables and energy storage where appropriate will be reviewed to flexibly support grid demand (centralized or distributed grids) and other energy applications, including but not limited to district/space heating, industrial process heat supporting chemical processes, and hydrogen production. The insights gained may identify technology solutions or modes of system operation for both established and developing nations, including those new to nuclear energy systems.

The CRP is aimed at further advancing the state-of-knowledge pertaining to modeling, simulation, and analysis approaches for design and optimization of nuclear - renewable HES and is intended to support development of data and analysis with the goal to advance these systems toward commercial deployment. The newly developed knowledge will be shared with Member States through various activities, such as but not limited to support of graduate students, participation in training workshops, and participation in case studies.

Duration

- 3 years
- Expected starting date: January 2022

Background Situation Analysis

Two main options for low emission energy are nuclear and renewables. However, synergies between these energy generation options still need to be fully characterized and utilised, and the advantages and challenges of integrating these generation options are only now being explored. Nuclear - renewable HES intend to exploit the opportunity to couple these energy resources to take advantage of benefits offered by each technology to supply reliable and sustainable electricity to the grid while also providing low emission energy to other energy sectors.

Driven by economics alongside sustainability and social development concerns, the global energy mix supporting electricity generation is undergoing a transition to include an increasing contribution from renewables. This systemic transformation to a low emission energy future has a high level of political support and funding in many countries [1-7]. While introducing new challenges (e.g., increasing the need for dispatchable, low emission energy resources), the ongoing transformation also presents potential synergies and opportunities for development of a more equitable and inclusive energy system that is environmentally sustainable, safe, reliable, and affordable, while also supporting enhanced grid resilience. Specifically, the proposed coupling and/or tighter integration of nuclear and renewable resources appears to be mutually beneficial. Heat, electricity, and other energy products or services could be produced and, as appropriate, stored by nuclear - renewable HESs, while enabling higher penetrations of variable renewable energy sources and introducing low emission sources to support non-grid energy users. In addition to electricity, nuclear - renewable HESs can deliver energy to various applications, such as hydrogen and hydrocarbon production, district heating or cooling, the extraction of tertiary oil resources, seawater or brackish water desalination, and process heat applications, including cogeneration, coal-to-liquids production and refining, and synthesis of chemical feedstock (e.g., ammonia).

Technical analyses using appropriate modelling tools are needed to assess the viability of the proposed energy systems. Currently, many of these analyses are performed using steady state simulation tools to first determine the appropriate energy balances within a proposed system. These analyses are then followed by more detailed dynamic analyses to predict energy flows in real time to optimize the system configuration, component sizing, and energy dispatch to electricity production to meet grid demand or energy delivery to the coupled processes [8-10], while adhering to technical constraints associated with the operation of the diverse set of subsystems.

Considering the novelty of nuclear - renewable HES, a full set of technical constraints and representative energy system figure-of-merit (FOM) still need to be established. Appropriately defined FOM and constraints are necessary to and evaluate the role of nuclear-renewable HES, operating alongside independent generators, in current and future energy systems. Significant improvements in methodologies and simulation tools are necessary to allow inclusion of multi-input and multi-output systems, applications, and products in the analysis while keeping the analysis tractable [11, 12]. Specifically, the advancements in the analyses of how the coupling between nuclear and renewable systems impact the current fleet of operating reactors and the

designs of advanced and innovative reactor designs in different regions as well as developed and developing countries; this represents the basis for this CRP.

The potential opportunities and benefits for nuclear - renewable HES in various energy markets still need to be further assessed. This has to be done vis-à-vis the other proposed energy options to fulfil electricity and other energy sector demands, consistent with the established climate and environmental targets, social development goals, regional and national energy policies, and at an affordable price.

Finally, international cooperation and training of students, early-carrier and female researchers have to be further fostered and enhanced to improve capabilities of Member States to evaluate the potential role of these novel systems.

Relevant References

[1] Flexible Nuclear Energy for Clean Energy Systems, Technical Report, NREL/TP-6A50-77088, September 2020.

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[8] FRICK, K.L. et al., Evaluation of Hydrogen Production Feasibility for a Light Water Reactor in the Midwest, Idaho Falls, ID, United States, 2019.

[9] BOARDMAN, R.D., et al., Evaluation of Non-Electric Market Options for a Light-Water Reactor in the Midwest, Idaho Falls, ID, United States, 2019.

[10] EPINEY, A.S., CHEN, J., RABITI, C., Status on the Development of a Modeling and Simulation Framework for the Economic Assessment of Nuclear Hybrid Energy, Idaho Falls, ID, United States, 2016.

[11] ARENT, D., BRAGG-SITTON, S., MILLER, D., et al., Design and Optimization of Novel Multi-Input, Multioutput Hybrid Energy Systems for a Clean Energy Future, *Joule*, 2020, https://doi.org/10.1016/j.joule.2020.11.004.

[12] U.S. DOE, *Grid Modernization: Metrics Analysis (GMLC1.1)*, Reference Document, Version 2.1, U.S. DOE Grid Modernization Laboratory Consortium, May 2017. https://www.researchgate.net/profile/David_Anderson86/publication/326132108_Grid_Modernization_Metrics_Analysis_GMLC11_Reference_Document_Version_21/links/5b3aa4f90f7e

9b0df5e8270d/Grid-Modernization-Metrics-Analysis-GMLC11-Reference-Document-Version-21.pdf

[13] IAEA, Non-baseload Operation in Nuclear Power Plants: Load Following and Frequency Control Modes of Flexible Operation, IAEA Nuclear Energy Series NP-T-3.23, 2018.

Scope of the CRP

This CRP will bring together the current state-of-knowledge on simulation, analysis, optimization, and potential deployment of nuclear - renewable HES that has been accumulated by experienced researchers, analysts, and industry with the aim of increasing understanding of the role, performance, and impact of nuclear-renewable HES in meeting current and future energy demands. The objective is to technically evaluate and optimize the options for coordinated use of nuclear and renewable energy and their tight integration in HES in meeting a range of current and future national and regional energy needs, and with this to foster national excellence and promote international collaboration among the IAEA Member States. As such, the CRP will:

— Define relevant figures of merit for energy systems in meeting both electric and non-electric energy demands, focusing on technical evaluation and optimizations;

— Develop or achieve significant improvement in methodologies, application of analysis tools, and interpretation of results to assess the role of nuclear-renewable HES in current and future energy systems;

— Enable inter-model comparison studies across various energy system analyses applied and demonstrations planned or implemented by participating Member States, leading to new knowledge and sharing of results relevant to technical evaluation and optimizations of nuclear-renewable HES;

— Identify and assess opportunities for and potential benefits of nuclear-renewable HES, relative to other energy system options and established figures of merit, to support grid and non-grid energy demands and carbon emission targets;

— Foster national excellence and international cooperation by elevating capabilities to assess the potential role of novel nuclear-renewable HES; and

— Promote knowledge sharing on nuclear-renewable HES for both developed and developing countries.

Participants in the CRP are expected to have active programmes on renewables and/or nuclear programme development, simulation tool uses and benchmark capabilities. As part of the research proposal, the attached questionnaire must be completed and attached to the research proposal.

This IAEA CRP is coordinated with other parallel international activities to avoid duplication and provide synergies to advance the state-of-the art and widen the knowledge base on nuclear-renewable HES.

CRP Specific Research Objectives

1. Review methodologies and data available for technical analysis of nuclear - renewable HES configurations to evaluate the role(s) and potential opportunities of these novel systems in future energy sectors —both grid and non-grid energy demands and carbon emission targets;

2. Identify gaps and applicability of available methodologies, tools and data to assess technical aspects of nuclear - renewable HES alongside traditional generators;

3. Develop case study/ies to analyse and assess the impacts of integrating renewables with nuclear power plants, on both, the current fleet of large unit reactors and on the design of advanced and innovative reactor concepts;

4. Define high level recommendations and outline the best practices in order to establish guidance for technical analysis and optimisation of nuclear - renewable HES;

5. Train early-career and female engineers and scientists and establish opportunities for MS/PhD research; develop and conduct workshops and training courses on nuclear - renewable HES.

Activities

A. Submission of research proposals for evaluation 1 October 2021

B. Participation in 1st Research Coordination Meeting (RCM): March 2022

Participants should be prepared to present material on expertise and experience in the following topical areas:

— Status and scope of existing energy system design and analysis tools applied within a region or Member State;

— Status of national or regional energy policies influencing energy system planning;

— How advanced reactor designs will be affected by their integration with renewables within tightly coupled HES;

— Description of gaps and challenges in cross-sectoral, multi-scale planning, design, and analysis tools;

— Recommendation for improvement of the existing planning and analysis methodologies or data collection;

— Status of feasibility assessments or early demonstrations of nuclear-renewable HES;

— Potential FOMs, analysis case(s), and/or inter-model comparison studies;

— Proposed engagement of young professionals, specifically graduate students and promotion of female students and professionals in this field;

— Other aspects related to CRP scope or objectives.

C. Develop to start implementing the CRP *umbrella* in supporting graduate programmes across the CRP members and the CRP *scheme* in supporting young and female professionals and graduate students March 2022

D. Participation in 2nd RCM March 2023

E. Participation in 3rd RCM March 2024

F. Develop and conduct training workshops, develop eLearning modules 2022,2023

G. Written submissions to Final Report (e.g., TECDOC, NES) 2024

H. Technical review of Final Report (e.g., TECDOC, NES) 2024-2025

CRP Outputs

1. IAEA publication (e.g., TECDOC, NES) and associated pamphlet or booklets;
2. Relevant training workshops, courses and supporting lecture materials, and learning tools to be developed;
3. Publications in conference proceedings and peer reviewed journals; and
4. MS/PhD training programme within the CRP to strengthen promotion of research on nuclear-renewable HES in developing Member States through pair building between agreement holders and contract holders institutes

CRP Outcomes

1. Improve capabilities and expertise in Member States to perform energy system planning and analysis/optimization to include electric and non-electric applications of nuclear - renewable HES;
2. Enable collaboration among nuclear, renewable, energy storage, and end use sectors on synergistic R&D;
3. Establish a common understanding and enable assessment of key figures of merit for evaluation of energy system options with nuclear - renewable HES;
4. Enable Member States to provide policy and decision makers with confidence to make evidence-based decisions on future energy expansion; and
5. Provide technical basis, within the context of energy markets and market transitions, for future demonstration of nuclear - renewable HES technologies.

Funding

The IAEA will contribute €3,000 per year towards each contract and support financially the attendance of CRP participants that have made substantial contributions (through contract or agreement) in the three research coordination meetings (RCM) planned to be held during the CRP lifetime.

Application Procedures

Interested scientists should submit their research contract or research agreement proposal that cover part(s) or all of the scope of the CRP, along with the completed questionnaire attached (the scope of the coverage of a proposal is to be determined by the Project Officer after evaluating the proposal and the capacity of the scientist(s) involved and the capability of the institute). The standard research contract/agreement proposal form is available at http://cra.iaea.org/cra/forms.html.

Research proposals should be submitted by email to Official.Mail@iaea.org by 1 October 2021.

Any administrative question should be addressed to the Research Contracts Administration Section (NACA) via research.contracts@iaea.org .

Technical enquiries should be addressed to the project officers for this CRP, Ms Tatjana Jevremovic (T.Jevremovic@iaea.org) and Mr Ed Bradly (E.Bradley@iaea.org).

Further general information relating to the participation in CRPs and the Coordinated Research Activities in general is available on http://cra.iaea.org.