

Education, Training and Research at Khalifa University in Support of the United Arab Emirates Nuclear Power Program

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Abstract— In 2009 United Arab Emirates (UAE) has engaged in an ambitious nuclear power program with the construction of four 1400 MWe pressurized water reactor units at the Barakah site. Fourteen years later, three units are in commercial operation, and the fourth one is in the final steps of commissioning. The four units will produce up to 5600 megawatts of electricity, supplying approximately 25% of the UAE's electricity requirements.

To ensure in such a short period of time the building of the nuclear capabilities and support to the program, Khalifa University has been, since 2010, a key contributor to education and training activities as well as the development of R&D capabilities in the field of nuclear technology.

This paper provides an overview of Khalifa University's activities implemented within the Nuclear Engineering Department, the Gulf Nuclear Energy Infrastructure Institute and the Emirates Nuclear Technology Center (ENTC). This joint Center, which embarks the Emirates Nuclear Energy Corporation and the Federal Authority for Nuclear Regulation, is a hub that addresses the research requirements of the nuclear stakeholders for the delivery of safe and efficient nuclear energy as well as the deployment of advanced nuclear technologies in the UAE. The paper briefly describes the current research projects implemented at the ENTC and gives reference related recent publications.

Keywords — United Arab Emirates nuclear power program, Capacity building, Academic education, Vocational training, Research program.

I. INTRODUCTION

THIS paper provides an overview of the education, training and research activities that have been implemented, since 2010, at Khalifa University in Abu Dhabi, to support the deployment of the nuclear power program (NPP) in the United Arab Emirates (UAE). Section II briefly describes the UAE nuclear power program with its objectives and status. Section III and IV are dedicated, successively, to the academic program in Nuclear Engineering and to the vocational training in nuclear infrastructure that were implemented for capacity building in support of the deployment of the NPP program. Section V provides an overview of the research activities developed at Khalifa University and at the recently established Emirates Nuclear Technology Center (ENTC) that involves not only

Khalifa University but also the Emirates Nuclear Energy Corporation (ENEC) and the Federal Authority for Nuclear Regulation (FANR). Concluding remarks and future perspectives and objectives are addressed in Section VI.

II. UAE NUCLEAR POWER PROGRAM

In 2008, UAE has taken the decision to go nuclear and embark in an ambitious nuclear power program after releasing its policy on "The evaluation and potential development of peaceful nuclear energy" [1]. Having no previous involvement in a nuclear program, the infrastructure and capacity had to be built from scratches to achieve the goal of producing 25% of electricity with nuclear power by 2030 and contributing to the UAE Net Zero objective for 2050.

In 2009 UAE issued its nuclear energy law and contracted KEPCO for the construction of four APR1400 units, 1400 MWe pressurized water reactors. In July 2012 started the construction of the Barakah Nuclear Power Plant (BNPP) located on the sea side, 250 km to the West of the Capital Abu Dhabi.

Nine years later, in April 2021 the first unit came into commercial operation, soon followed, in March 2022 and February 2023 by the successive commercial operation of units 2 and 3, respectively. As of August 2023, the project reaches a completion rate of 98 % while the hot functional tests of unit 4 have been completed in July 2022 and commercial operation is expected in the coming months. As planned the four units are to produce a total of 5600 MWe representing 25% of the UAE electricity and contributing to decarbonization.

As a new comer in nuclear power with no previous nuclear infrastructure, UAE has demonstrated that it is possible in a period of 15 years to fully implement a nuclear power program from the implementation of the infrastructure to the commercial operation of the plant.

This very ambitious objective was achieved through an efficient establishment of the regulation, building of the capabilities as well as management of the industrial project. To ensure an optimized implementation of the project. It is also important to highlight that UAE has been following the milestone approach [2] of the International Atomic Energy Agency (IAEA) and has benefited from its assistance in the various domains of the nuclear infrastructure.

In the field of capacity building Khalifa University has been

and is playing a major role supporting the nuclear power program with three pillars described in the following sections: the academic program in nuclear engineering, vocational training and research activities adjusted and focused according to the specific needs of the UAE program.

III. NUCLEAR ENGINEERING ACADEMIC PROGRAM

Following the decision to go nuclear in 2008-2009, the nuclear engineering academic program was launched at Khalifa University with its Nuclear Engineering Department, in September 2010, with an MSc degree in Nuclear Engineering. It was followed in 2012 with the introduction of Nuclear Engineering Minor into the BSc degrees in other engineering disciplines such as mechanical, chemical and electrical engineering. A PhD program with a concentration in nuclear engineering was also launched in 2012. It is important to note that these programs until 2021 have been open only to UAE nationals expressing the priority given to develop the national capabilities.

The nuclear engineering program has been established and further developed in coordination with the key nuclear stakeholders, i.e. ENEC, FANR and lately Nawah, the operating organization of the BNPP. It has been supporting the development of the human resources as needed along the implementation of the nuclear power program. It is important to mention that, until 2020, a majority of the MSc students were part-time students employed by one of the key stakeholders going through nuclearization but potentially having a work experience in other engineering and energy fields.

According to the needs, areas addressed in the nuclear engineering programs includes:

- Reactor Physics,
- Neutronics, Thermal Hydraulics,
- Nuclear Fuel Cycle,
- Nuclear Safety, Security, Safeguards,
- Nuclear Materials and Chemistry,
- Radiation metrology, Radiological protection & impact,
- Nuclear waste.

To take into account the diversity of profiles identified by the stakeholders, the MSc program integrates, which combines core and elective courses, exhibits five tracks, namely: Nuclear systems and probabilistic safety assessment, Nuclear reactor design, Nuclear safeguards, security and the fuel cycle, Nuclear material and radiation damage, and Nuclear and radiation Safety.

It is also to mention that the educational program is underpinned by research activities since students are heavily involved in research projects meeting the needs of the stakeholders and implemented within the ENTC (see section V).

IV. VOCATIONAL TRAINING IN THE NUCLEAR FIELD

In 2011 the Gulf Nuclear Energy Infrastructure Institute (GNEII), a Gulf and Middle East regional human resource development capability, has been launched to be hosted at Khalifa University. The institute was established as the result of a strategic partnership between UAE stakeholders, namely

Khalifa University, ENEC and FANR, and USA partners, Sandia National Laboratories and the Nuclear Security Science and Policy Institute at Texas A&M University.

GNEII was initially implemented as a continuing education and research entity with a focus on the so called 3 S concept, which stands for Safety/Security/Safeguard, and with the objective of developing the nuclear energy infrastructure knowledge and expertise, a 13-week program being regularly run every year.

To meet the current needs of the UAE stakeholders, i.e. at the advanced stage of the nuclear power program, the scope and objectives of GNEII are currently been revised. From 2024 a broad range of one- to two-week training modules will be offered, covering basic nuclear knowledge to specialized nuclear topics, modules being organized under six sub-areas:

- Basic knowledge (entry modules),
- Nuclear reactors,
- Nuclear fuel cycle,
- Nuclear safety and licensing
- Nuclear security and safeguards,
- Nuclear project management.

Additionally, since 2016 Khalifa University is a designated IAEA Collaborating Center. As such and in collaboration with UAE nuclear stakeholders, Khalifa University assist the IAEA in implementing its programmatic activities, hosting workshops, training courses, fellowship trainings and scientific visits. The Center also provides the opportunity for UAE to share resources, knowledge and expertise with the IAEA Member States. This is an important role of the Center now that UAE can share its newcomer experience after having successfully managed, in a short period of time to development of its nuclear infrastructure and implementation of its nuclear power program.

Furthermore, in 2022, Khalifa University has signed a Practical Arrangement with the IAEA for the development and the implementation of training courses and a post graduate program and certificate in nuclear law. This training opportunities will address both technical aspects and the legal framework related to nuclear reactors. Such a holistic approach is necessary to facilitate the deployment of nuclear power applications including Small Modular Reactors and micro-reactors.

V. RESEARCH AT THE EMIRATES NUCLEAR TECHNOLOGY CENTER

Research activities in the nuclear domain have been initially performed at Khalifa University under the Nuclear Engineering Department. With the progression of the nuclear power program and the expansion of the needs in research activities the key nuclear stakeholders, i.e. ENEC, FANR and Khalifa University took the decision to launch in January 2020 the Emirates Nuclear Technology Center (ENTC). This joint Center operated and funded by the three entities is embedded in Khalifa University, which represents the legal entity. The Center located within Khalifa University, is a hub to address the research requirements to support the UAE's Nuclear Power

Program. Research activities and projects are implemented under four thematic areas whose objectives are described here after.

Theme 1, Nuclear systems & safety, is dedicated to neutronics & thermal hydraulic studies in relation to the safe and optimal operation of NPPs with a focus on BNPP. This theme aims to assess the thermal hydraulic safety analysis codes by validating their predictions against experimental data obtained from integral effect test facilities. This is intended to identify and validate dominant thermal hydraulic phenomena occurring in NPPs under postulated accident scenarios, including rare events. The theme is also focusing in applying computational reactor physics codes for safety analysis and operation of the advanced pressurized water reactor APR1400 as well as innovative reactor designs. The main drive for selecting these topics is that thermal hydraulic and neutronics studies on, beyond design-based accident for the APR1400, is one of the immediate necessities that the UAE nuclear program needs to develop to guarantee a safe operation of these power plants.

Theme 2, Nuclear materials & chemistry, is dedicated to the optimization of the NPP operation and availability in relation to the structures, systems and components integrity keeping in mind the 60 + year operation. Most materials in NPPs undergo various degradation phenomena under operation and by ageing. The type and degree of the degradation depends on the operational conditions including environmental, mechanical, and materials conditions. Since such material degradation under operation and by ageing can affect either the maintenance program, i.e. the frequency of testing, maintenance or replacement of components, as well as the structural integrity of components, material degradation needs to be understood in a comprehensive way and managed in the most effective way.

Theme 3, Radiation safety & the environment, is dedicated to radiation measurement and the modeling of the impact of radiation on the environment and the public. The construction and operation of NPPs, as well as the development and implementation of nuclear methods and techniques, are associated with the risk of release of radioactive materials than can affect the sensitive regions and population. Experimental data and numerical tool are used to map the ecosystems during normal and abnormal situations with a particular focus on BNPP and the Gulf region. This theme also addresses studies related to the influence of the operation of the BNPP on the environment and vice versa, with the objective of reducing the impact and optimizing the NPP performances.

Theme 4, Advanced nuclear technology, has been introduced at the beginning of 2023. While the three first themes were initially developed with a focus on supporting the BNPP safe and effective operation, Theme 4 aims at broadening the research activities to a large variety of applications of nuclear technology and advanced technologies that can improve nuclear technologies. Foreseen activities encompass small modular reactors, nuclear cogeneration, nuclear security, emergency preparedness, as well as nuclear applications in the health sector, water management, agriculture and food sector, forensic, to which can be added the utilization of advanced manufacturing, Artificial Intelligence and Machine Learning

and other advanced technologies that can benefit nuclear technology.

It is important to highlight that research activities implemented under the ENTC are primarily focused on the UAE-specific technology, environment and related needs. For example, there is a need to study the impact of the UAE harsh conditions, due to high temperatures, humidity, salinity, dust and sand, that impact the APR1400 reactors structures, components and operation. Also, radiation mapping, both natural and anthropogenic, and the modeling of radionuclides dispersion including environmental migration and bioaccumulation, are UAE-specific and needs to be extensively studied taking into consideration that the transfer of radionuclides in arid environments is not yet comprehensively documented.

For the first three-year cycle of the ENTC (2020-2022) goals and achievements can be summarized as follow:

- Research activities focusing on end-user and industry driven projects for ENEC, Nawah and FANR with a focus on UAE specifics;
- 15 research projects implemented and agreements finalized to start 6 additional projects at the beginning of 2023;
- Total amount of fund engaged over the period, \$ 20 M, including matching funds from international partners;
- Partnership with UAE entities, such as Technology Innovation Institute, Borouge Ltd, Union Pipe Industry, as well as international partners such as Korea Atomic Energy Research Institute, Korean Advanced Institute of Science and Technology, Massachusetts Institute of Technology, University of Birmingham, University of Manchester, Institut de Radioprotection et de Sûreté Nucléaire, Institut Mines Telecom Atlantique;
- Effective capacity building with the involvement of about 30 faculty members, researchers and postdocs, as well as 30 PhD and MSc students, the latter being UAE national in a large majority;
- Development of experimental capabilities, the ENTC exhibiting 4 Laboratories, namely the Computation and simulator Lab, Heat transfer Lab, Nuclear material and chemistry Lab, Radiation metrology and Environmental Lab. Note that the ENTC also benefit from Khalifa University core laboratories and capabilities of other Centers for cross-cutting activities.

Here after is a synthetic overview of the research areas of the projects currently implemented under the four thematic areas of the ENTC. Insight into the recent development and achievements of research projects implemented under the ENTC can be found in [3 – 23]

Theme 1 - Nuclear Systems and Safety

- Evaluation and selection methodology of Accident Tolerant Fuel for the APR1400 reactor
- Code development and validation for the prediction of rare events in the APR1400
- Flexible and efficient APR1400 reactor operations through integration of energy storage
- Validation of safety analysis code and assessment of thermal-hydraulic behaviors of APR1400

Theme 2 - Nuclear Material and Chemistry

- Enhancement of corrosion and wear resistance of cooling water components for the APR1400
- Prediction of degradation in concrete structures by sulphate attack and development of remedial measures
- Development of a multi-physics computational modelling framework and experimental procedure of butt fusion welding of large HDPE pipes

Theme 3 - Radiation Safety and the Environment

- Marine environment monitoring for the BNPP
- Anti-fouling remediation strategies for water intakes for nuclear reactor cooling systems
- Biological treatment of ethanalamine-rich wastewater from NPPs
- Radionuclide dispersion modeling in the UAE environments and inverse modeling (origin/magnitude)
- Transport of radionuclides in the UAE environment (emergency preparedness, siting and design of new nuclear facilities)

Theme 4 – Advanced nuclear technology

- User driven approach and technology development for an effective deployment of small modular reactors
- Quantum-inspired algorithms for nuclear reactor physics and computational fluid dynamics

VI. CONCLUDING REMARKS AND FUTURE PERSPECTIVES

UAE rapidly went from the statute of new comer in nuclear power to a country operating its first nuclear power plant that will provide very soon, when the 4th unit will enter into commercial operation, 25 % of the electricity.

Starting from very limited nuclear capabilities UAE has proven that a nuclear program can be successful implemented in a period of 15 years from the development of the nuclear infrastructure to the commercial operation of the plant.

This success relied upon extensive capacity building activities in which Khalifa University played a major role with its academic program and vocational training in nuclear engineering, as well as with the deployment of research activities in support of the UAE nuclear power program.

An important step to reinforcing capacity building and to provide a dedicated support to the nuclear program was taken in 2020 with the creation of the ENTC that embarked the nuclear energy corporation - ENEC - and the regulatory body – FANR. This step forward was decisive in amplifying the research and development efforts in support of these stakeholders.

To meet the current and future UAE needs perspectives and objectives includes the adjustment and expansion of the academic and professional training to meet the needs of the nuclear power program and the further development of nuclear applications in the UAE. For research activities, key objectives are: (1) to further develop the national research capabilities, both human and experimental, with a focus on the UAE and Gulf region specifics; (2) to expand the scope of the research activities to advanced nuclear technologies, as defined in

Theme 4; (3) to further develop international collaboration to leverage capacity building and international expertise as well as to facilitate the access to experimental facilities and; (4) to become a nuclear actor sharing UAE experience and expertise in the deployment and operation of NPPs that can benefit newcomers in deploying or developing their nuclear power program.

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