Characteristics and Capabilities of the Saudi Low Power Research Reactor (LPRR)

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Abstract –
The Saudi Low Power Research Reactor (LPRR) is one of the prominent Saudi Vision 2030 projects. It is a pool-type multipurpose low power nuclear reactor designed and developed by King Abdulaziz City for Science and Technology (KACST) with the participation of international expertise in accordance with the best and highest international safety standards. The reactor is under construction and expected to be fully commissioned by mid-2024. In line with the Saudi Vision 2030, the Saudi LPRR will thoroughly contribute to the innovative design and development of the nuclear reactor industry in the Kingdom, developing and qualifying competencies and building human capacity to operate nuclear power reactors, and transferring nuclear energy technologies. The LPRR is equipped with several attractive facilities with various capabilities and designed as a multipurpose low power reactor to support demands on research, education, training for building human capital, and developing the competencies to support the country's national atomic energy project. In this paper, the main characteristic of the Saudi LPRR will be presented in terms of the reactor core design, main utilization, and training capabilities.

Keywords: Research Reactor, Nuclear Education and Training, Neutron Physics Experiments, Utilization

I. Introduction

Research reactors (RRs) are nuclear reactors that are typically much smaller and simpler in design compared to nuclear power reactors making them safer and easier to operate [1]. They are used for a variety of research, development, education, and training purposes. They produce neutrons that can be used for a wide range of applications, including isotope production, materials testing, and neutron scattering. RRs also play an important role in nuclear capacity building, by providing countries with the opportunity to develop the skills and knowledge needed to operate and use nuclear technology safely and responsibly [1].

To build the best future for the Kingdom of Saudi Arabia, His Royal Highness Crown Prince Mohammed bin Salman bin Abdulaziz has launched the Saudi Vision 2030 which is a strategic framework built around three themes: a vibrant society, a thriving economy, and an ambitious nation [2]. To highlight the Kingdom's efforts toward economic, social, and cultural diversification which are represented the crown jewel of Vision 2030, various Saudi Arabia's projects have been planned and established. Each of these projects will open new areas of economic activity, create jobs and drive economic development in line with Vision 2030 [2]. One of the prominent Vision 2030 projects is The Saudi Low Power Research Reactor (LPRR) [3]. The Saudi LPRR is first of its kind in the Kingdom of Saudi Arabia and in the Gulf region, contributing to the innovative design and development of the nuclear reactor industry in the Kingdom, developing and qualifying competencies and building human capacity to operate nuclear power reactors, and transferring nuclear energy technologies. The Saudi LPRR project is under construction at the campus of King Abdulaziz City for Science and Technology (KACST) in city of Riyadh and expected to be in full operation by 2024.

The reactor specifications were designed and developed by KACST with the participation of international expertise in accordance with the best highest international safety standards. The major objectives of the Saudi LPRR are as follows,

- Transferring nuclear reactor technologies including the design, construction, commissioning, operation and maintenance, and decommissioning stages.
- Establishing cutting-edge nuclear energy training and education facilities for the development of the national capabilities in the field of nuclear energy.
- Enabling innovation, scientific research and technology development activities in nuclear science and engineering and related fields.

In this paper, the main characteristic of the Saudi LPRR will be presented in terms of the reactor core design, main utilization and capabilities.

2. REACTOR CORE DESIGN

The reactor is a pool type design which means that the core is located inside a pool of de-mineralized water that provides both cooling and biological shielding for radiation from the core. The Reactor Pool is 8.5 m deep and 2.5 m in diameter. The internal components of the pool are: lower and upper core grids, neutron beam tube, graphite reflector control rod storage rack and pneumatic rig storage rack, nuclear instrumentation, fuel rods racks, internal pipes and supporting structure.

The reactor core has two grids (upper and lower) which provide 1300 positions to accommodate a variable number of fuel Rods, six Control Rods Assemblies and channels for experiments. The fuel rod is a cylindrical shape fuels where each fuel rod consists of low enriched uranium pellets enclosed in a Zircalloy-4 cladding. The Saudi LPRR core can operate in two modes: Nominal Power Mode (up to 30kW) and Overpower Mode (up to 100kW) with very low inventory of radioactive material. This low power is the key safety feature: when the power of the core is compared with the size of the core and the inventory of coolant, the margins towards the fuel design limits are large enough to accommodate the transients following all the Design Basis scenarios and all the foreseeable scenarios with multiple failures (Beyond Design Basis). Further, the limitation of the core reactivity excess to a value lower than 1 dollar prevents prompt critical accidents. Shielding throughout the facility maintains radiation levels to operating personnel and to the general public within the applicable limits set forth in the appropriate standards and in compliance with the As Low As Reasonable Achievement (ALARA) principle.

The reactor is controlled by six control rods belonging to the reactor shutdown system. Each control rod consists of a set of 3 absorber rods made of hafnium pellets into a Zy-4 cladding. A neutron reflector made of nuclear grade graphite lined with aluminum is attached to the beam tube to improve the thermal neutron density in this region. The thermal neutron flux at the center of the core can reach a value of 1.51×10^{12} n/cm^2.s while the fast flux can reach a value of 2.8×10^{12} n/cm^2.s. Such relatively high flux values are adequate to perform a wide variety of experiments and production of thermal neutron beams for scientific research and the irradiation of samples as well.

3. THE SAUDI LPRR CAPABILITIES AND APPLICATIONS

The Saudi LPRR is designed as a multipurpose low power reactor with various industrial and academic analytical capabilities. While the primary use of the reactor is the education and training of nuclear professionals and technicians, the reactor is also qualified to produce neutron beam for research and the irradiation of materials for analysis and assessment.

The Saudi LPRR is capable to carry out reactor physics experiments, health physics and radiation protection dosimetry, and irradiation services. Further, the reactor is able to operate neutron beam facilities that provide wide range of capabilities including unique non-destructive testing and characterization and perform neutron physics research. Highest safety provisions have been considered during the operation of systems and components of each of those utilization facilities and experiments. Below are the main utilization capabilities: [4]

3.1 Reactor Physics Experiments

Reactor physics experiments are the practical investigation of the processes that occur at the core of nuclear reactor which provide detailed information required for the successful design, construction and operation of any nuclear reactors. Various reactor physics experiments can be performed at the Saudi

LPRR. To name a few, below are some major reactor physics experiments that can be performed in the Saudi LPRR:

- *Neutron Flux Measurements*
- *Online measuring of the core reactivity*
- *Neutron multiplication measurement*
- *Fuel substitution techniques*
- *Asymptotic period measurements*
- *Rod drop method*
- *Source jerk method*
- *Rod oscillator method*
- *Pulsed neutron methods*
- *Dynamic prompt power coefficient of reactivity*
- *Determination of void coefficient of reactivity*
- *Control Rod Calibration*
- *Noise analysis in nuclear reactors*
- *Neutron flux perturbations*
- *Fission products spectrum*
- *Reflector Analysis*
- *Neutron Poisoning Experiment*

In addition to the above real-time rector physics experiments, the Saudi LPRR is equipped with a Nuclear Reactor Simulator: which is a sufficient tool for real-time simulation for training on the reactor physics. The simulator consists of screens with reactors variables emulating the Reactor Control and Monitoring System (RCMS) enabling exercises evaluating different reactor variables (neutron population, core power, core temperatures, analysis of physical parameters such as precursors population, fission products build up, fuel burnup, etc.).

3.2 Health Physics and Radiation Protection Dosimetry

Health physics and radiation protection dosimetry is the career and profession devoted to protecting people and their environment from potential radiation hazards, while making it possible to enjoy the beneficial uses of radiation. The Saudi LPRR is capable to provide various applications to the field of the health physics and radiation protection dosimetry including: portable radiological protection services, onsite surveys, spectrometry, checking sources as well as quantitative air monitoring capabilities.

3.3 Irradiation Facilities, Services and Labs

- Neutron Activation Analysis Facility:

Neutron activation analysis (NAA) is a sensitive analytical technique for determining the determination of trace elements/impurities in a sample. The technique is most accurately recognized as a method of quantitative chemical analysis based on the nuclear properties of constituent elements. NAA can be used for a large variety of applications, for example in archeology, biology, trace elements in oil, lipids and petrochemical samples, chemistry, geology, forensics etc.

One of the essential capabilities of the Saudi LPRR is to operate a Neutron Activation Analysis Facility. Samples can be irradiated with neutron flux in three positions and then analyzed in a gamma radiation spectrometer. One position is in the center of the reactor core and two in the graphite reflector. Two of the irradiation positions, at the core center and in one of the reflector blocks are accessible with the Pneumatic Rig. The control of the activation can be done by means of the Pneumatic Transfer System (PTS). The PTS is operated from the NAA terminal station, which is located in the NAA laboratory. The irradiation can be done at positions providing different profiles and magnitudes of neutron flux. It is achieved by setting the Pneumatic Rig in the desired position when the reactor is in a shutdown state. The system makes possible to control the neutron fluence over the irradiated can. Further, the system can be also used to irradiate cans with gamma-ray radiation only with the reactor in shutdown state.

- Radiochemistry Lab:

Understanding radionuclide behavior in the natural environment is essential to the sustainable development of the nuclear industry and key to assessing potential environmental risks reliably. The Saudi LPRR is fully equipped with a state-of-art laboratory with the latest chemical analytical equipment for speciation studies of metals in aqueous, organic and micellar media.

- Material irradiation and testing:

The Saudi LPRR is very suitable to investigate the materials that are subject to intense neutron irradiation to study the induced changes. This would be able to reproduce material degradation undergone by materials in power reactors and provide essential support to the study of ageing of materials in existing nuclear power reactors and advanced new generation reactors.

-Isotope production: The Saudi LPRR is capable to be produces limited number of radioisotopes, typically applied in industry (Oil, gas, chemical, cement wastewater treatment plants and other industries) and/or medicine/veterinarian. Radiotracers can also be induced and produced in a typical low power nuclear reactor for the purpose of labeling process, dynamics and reaction kinetics, flow and residence time distribution, non-invasive monitoring, leak detection and compartmental studies, compounds and adsorption phenomena assessment.

3.4 Neutron Beam Facilities

The Saudi LPRR is equipped with a neutron beam port extracted form the core with a double static barrier between the Reactor Pool and the area outside the reactor block. At the outermost part of the Neutron Beam Tube, there is a shutter frame, embedded into the heavy concrete of the main biological shield, housing the shutter. The shutter has two main components: A fixed component and a rotating component, both made of a composite (Cast Steel + Pure Polypropylene) multilayer shielding. The rotating component has into its interior a continuation of the Neutron Beam Tube, the Shutter Beam Tube. The Neutron Beam Shutter has two positions, namely closed position, and open position. At its Closed Position, it ensures the required shielding equivalent to the provided by the Reactor Block. At its Open Position, it connects the Neutron Beam with the Beam Hall. The Neutron Beam Shutter at Open Position allows the execution of experiments in the Beam Hall.

Neutron beam facilities are located after the neutron beam shutter. There are three neutron beam facilities, namely, Neutron Radiography Facility, Neutron Time of Flight Facility (ToF), and Thermal Neutron Diffraction Facility. The whole facilities are located inside a Shielding Bunker Block made of concrete in steel frame to allow the opening of the Reactor Beam Shutter and make use of the neutrons extracted by the beam.

- Neutron Radiography Facility (NRF):

This technique makes it possible to make images with neutron flux. A method to do this can be based on the neutron attenuation properties of the imaged object. Neutron Radiography is a Non-Destructive Technique (NDT) which provides images similar to Electro Magnetic (EM) radiography but containing different and often complementary information to the provided by EM radiation. This is so due to the difference between neutron and X-ray interaction mechanisms with the matter: while EM attenuation is directly dependent on the atomic number, neutrons are efficiently attenuated by only a few specific elements. The Neutron Radiography facility of the Saudi LPRR can be equipped with state-of-art components including a) Neutron collimator b) Sample table/support. c) Neutron Screen d) Black chamber containing the Neutron Screen, mirrors and a CCD camera.

- Neutron Time of Flight Facility (ToF):

In neutron time-of-flight (TOF) scattering, a pulsed monochromatic neutron beam is scattered by a sample. By the principle of conservation of momentum, the energy spectrum of the scattered neutrons and the momentum and energy transferred to the sample can be inferred. TOF is a widely used technique, providing a valuable tool for nuclear scattering teaching and research. The main components of TOF facility are the following: a) Neutron moderator b) Neutron Beam Chopper. c) Flight tube d) High efficiency neutron detector, such as He3 detector or BF3 detector synchronized with the neutron beam chopper. e) Multichannel analyzer and data acquisition system

- Thermal Neutron Diffraction Facility (NDF):

This facility uses the application of neutron scattering to the determination of the atomic and/or magnetic structure of a material with wide range of applications including for example, very accurately measurements of the lattice constant of metals and other crystalline materials with high measured. The Thermal Neutron Diffractometer includes, the neutron beam channel interface, a monochromator unit with a mono-crystal and its shielding, followed by a secondary beam shutter and, finally, an out-going guide/collimator section. The monochromator-sample path consists of the following elements: monitor, collimator unit and remote-controlled slit. The sample unit consists of a rotating table for samples with special conditioning and beam stop for the direct beam halting. The detector unit is composed of an area detector, detector shielding and detector electronics. The unit is moved by a displacement mechanism, which are remotely controlled from the instrument computer. Shielding elements will be designed and manufactured to ensure biological protection limits and low experimental background.

4. CONCLUSION

The Saudi Low Power Research Reactor (LPRR) is one of the unique Vision 2030 projects and it is under construction at the campus of King Abdulaziz City for Science and Technology (KACST) in city of Riyadh. The reactor has large safety margins and flexibility. This gives the opportunity to use the reactor as the training tool for developing human resources in the nuclear engineering field. The Saudi LPRR are flexible to perform different activities such as reactor physics experiments, neutron activation analysis and training operators for commercial nuclear power plants.

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