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Experimental study of radiation dose rate at different strategic points of the BAEC TRIGA Research Reactor

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HIGHLIGHTS

- Radiation dose rate at different strategic points of the reactor was measured.
- Neutron leakage was identified at the piercing beam port measurement position.
- Radiation dose rate at the reactor pool top surface under NCCM and FCCM was measured.
- The measured dose rate under NCCM was obtained higher than FCCM.

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ABSTRACT

The 3 MW TRIGA Mark-II Research Reactor of Bangladesh Atomic Energy Commission (BAEC) has been under operation for about thirty years since its commissioning at 1986. In accordance with the demand of fundamental nuclear research works, the reactor has to operate at different power levels by utilizing a number of experimental facilities. Regarding the enquiry for safety of reactor operating personnel and radiation workers, it is necessary to know the radiation level at different strategic points of the reactor where they are often worked. In the present study, neutron, beta and gamma radiation dose rate at different strategic points of the reactor facility with reactor power level of 2.4 MW was measured to estimate the rising level of radiation due to its operational activities. From the obtained results high radiation dose is observed at the measurement position of the piercing beam port which is caused by neutron leakage and accordingly, dose rate at the stated position with different reactor power levels was measured. This study also deals with the gamma dose rate measurements at a fixed position of the reactor pool top surface for different reactor power levels under both Natural Convection Cooling Mode (NCCM) and Forced Convection Cooling Mode (FCCM). Results show that, radiation dose rate is higher for NCCM in compared with FCCM and increasing with the increase of reactor power. Thus, concerning the radiological safety issues for working personnel and the general public, the radiation dose level monitoring and the experimental analysis performed within this paper is so much effective and the result of this work can be utilized for base line data and code verification of the nuclear reactor.

1. Introduction

The BAEC TRIGA Research Reactor (BTRR) was designed to effectively implement the various fields of basic nuclear research, radioisotope production and education. It incorporates facilities for advanced neutron and gamma radiation studies as well as for research and development works, sample activation, and student training (BAEC Report, 2006). The BTRR was licensed on the basis that there will be no undue hazard or significant radiation effect on public health and safety. To minimize radiation exposure and to ensure safety for reactor operating personnel, radiological workers and general public it is important to investigate the radiation doses at different strategic points during the reactor operation with high power level. In the previous study (Moshiur Rahman et al., 2014) an experimental measurement was performed to measure the radiation dose rate in and around the Central Radioactive Waste Processing and Storage Facility (CWPSF) at Atomic Energy Research Establishment (AERE). An important part of the present study is the monitoring of different strategic points of the BTRR facility where radiation hazards may exist. Level of radiological hazard caused by alpha, beta and gamma radiation was assessed by

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performing radiation dose rate surveys. Alpha particles have only a very short range in air (a few cm), and are not considered an external radiation hazard since they can't penetrate the outer layers of the skin, therefore it was not measured. On the other hand, like gamma rays, neutrons are also highly penetrating. They give energy to the body as they are scattered in body tissues. Neutrons are an important external radiation hazard which requires careful control (Moshiur Rahman et al., 2014). Radiological control along with regulatory and management requirements at the operational level of the reactor is required for ensuring safe practices in the workplace of the reactor facility, as well as for the protection of the general individuals and the environment. With these practical considerations, the current experiments were carried out to detect the radiation type and measurement of radiation dose rates to radiological workers and general public. This paper summarizes beta, gamma and neutron dose rate measurements at various strategic points in BTRR to estimate the rising level of radiation due to its operational activities. As a part of the experimental works, dose rates were measured at the grating surface of the reactor pool top with different reactor power levels under NCCM and FCCM. The grating top surface of the reactor pool is usually used for the purpose of numerous experimental works such as radiation dose rate studies, which is often performed by the radiation workers and the reactor operating personnel. When the reactor is in operation, the water coolant flowing through the reactor core is exposed to an intense neutron flux which causes production of radioisotopes occurred by neutron reactions with water molecules, dissolved gases and impurities in water. Of the radionuclides produced in the water coolant, ^{16}N, ^{41}Ar, ^{19}O, ^{17}N, ^{3}H, and ^{14}C are assumed to be radiologically hazardous which are decayed by the emission of beta particles, gamma rays or neutrons. Among all of these radionuclides ^{16}N is radiologically most significant which contributes to elevated radiation levels due to high energy gamma radiation of about 6.13 MeV (Ajijul Hoq et al., 2016a).

When the reactor is in operation under NCCM, the radiologically most significant radionuclide ^{16}N produced in the reactor core may rise to the pool top surface which can cause direct radiation exposure to the reactor operating personnel by threatening their safety. But when the reactor is in operation under FCCM, part of the core water with produced ^{16}N passes through a decay tank which holds the radionuclides for about 143 s to allow them to decay to levels which do not make any harm to human health and the environment (BAEC Report, 2006). The radiation monitoring work performed for the experiment has been carried out using different gamma, beta and neutron survey meters. The measured radiation dose rate has been analyzed and evaluated to reduce the radiation risk on the individuals involved in the research reactor operation, maintenance and its utilization, including the visitors and the associated environment according to the IAEA safety series (BSS-115) and International Commission on Radiological Protection recommendation.

2. Brief description of the BAEC TRIGA Research Reactor

The BAEC TRIGA Research Reactor is a light water cooled, cylindrical shaped pool type research reactor which uses uranium-zirconium hydride fuel elements in a circular grid array. The reactor uses Low Enriched Uranium (LEU) fuel with enrichment of 19.7% ^{235}U, $ZrH_{1.6}$ (prime moderator) and burnable poison ^{167}Er (Ajijul Hoq et al., 2016b). The core is situated near the bottom of water filled pool and the pool is surrounded by a concrete bio-shield. The reactor pool is made of special aluminum alloy and has a length of 8.23 m and a diameter of 1.98 m, filled up with 24.865 m^3 of demineralized water (Rahman et al., 2014). Ion exchanger resin column filters the reactor pool water and stores ions produced in reactor coolant. The reactor core consists of 100 fuel elements (93 standard fuel elements, 5 fuel follower control rods (FFCR) and 2 instrumented fuel elements), 6 control rods (5 FFCR and 1 air follower control rod), 18 graphite elements, 1 Dry Central Thimble, 1 pneumatic transfer system irradiation terminus and 1 neutron source (Salam et al., 2014; Hosan et al., 2015). All of these elements are placed and supported in-between two 55.25 cm diameter grid plates and arranged in a hexagonal lattice. The reactor has been designed for operation under three operation modes namely, steady state mode, square wave mode and pulse mode. The steady state mode of operation could be performed under two cooling modes – (i) Natural Convection Cooling Mode (NCCM) and (ii) Forced Convection Cooling Mode (FCCM). The reactor can be operated up to power level of 500 kW under NCCM and under FCCM the reactor can be operated up to maximum power level of 3 MW. The reactor has four water system such as (1) Primary water system, (2) Secondary water system, (3) Emergency core cooling system (ECCS) and (4) On line purification system. The reactor cooling system is designed to maintain the flow of demineralized water through the reactor core at a rate of 13.230 m^3/min so as to remove the 3 MW thermal power being produced in the core from thermal fission (BAEC Report, 2006). The reactor is equipped with four beam ports. The beam ports penetrate the concrete shield and aluminum tank and pass through the reactor pool water to the reflector. These ports provide beams of neutron for a variety of experiments. The reactor is controlled by six control rods, which contain Boron Carbide (B_4C) as the neutron absorber material. The reactor is housed in a hall of 23.5 m × 20.12 m having a height of 17.4 m. The volume of the reactor hall is 8202.65 m^3 (BAEC Report, 2006). The different strategic points of the BAEC TRIGA Research Reactor is shown in Fig. 1.

Measurement Positions: 1-Public gallery (Glass wall surface), 2-Reactor control room (Glass wall surface), 3-Reactor Operator (RO) sitting chair, 4-Rail surface of the reactor top, 5-Grating surface of the reactor top, 6-Radial beamport-1, 7-Radial beamport-2, 8-Tangential beam port, 9-Piercing beam port, 10-Secondary pump room, 11-Shielding surface of ion exchanger resin column, 12-Surface of ion exchanger resin column, 13-Primary pump room, 14-Outside of the decay tank wall.

3. Measurement of dose rate and experimental analysis

3.1. Materials and methods

During reactor operation with maximum power 2.4 MW at the same time radiation dose rate was measured at different strategic locations by using calibrated digital survey meters. Dose rates were measured three times at each point in step of every three minutes with the same reactor operational condition. Observed dose rate and standard deviation of the survey meters were recorded and their average was taken as the total dose rate. Same procedure was repeated for recording dose rate data at the piercing beam port measurement position under different reactor power levels. During dose rate survey at the reactor pool top surface with NCCM due to experimental limitation survey meters were placed on the pool surface at a fixed position 20 cm apart from the pool center and recorded dose rate data in step of every three minutes and their average result was counted. The same procedure was followed for dose rate measurement during different reactor power (i.e. 0.005–2400 kW) operation with FCCM. The exposure time (3 min) was strictly maintained for every measurement.

Detection of neutron, beta and gamma radiation and measurement of dose rates triggered by them was performed by utilizing a set of measuring instrument. Name of survey meters used for gamma radiation monitoring and dose rate measurement were Graetz X5 DE (Manufacturer – Germany, Serial no. – 53079), Austra1Rad Mini8-in-1 (Manufacturer – Gamma sonic Australia, Serial no. – 1128) and DKS-96 (Manufacturer – Russia, Serial No. – 0292003). The name of the equipment used for neutron dose rate measurement was Neutron Survey Meter (Manufacturer – Thermo Scientific Germany, Serial no. – 9072/2616). Before dose rate measurement all measuring equipment were calibrated in the Secondary Standard Dosimetry Laboratory (SSDL) of Institute of Nuclear Science and Technology (INST). The errors were always below 5% during the calibration. For calibration