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Estimation of ^{41}Ar activity concentration and release rate from the TRIGA Mark-II research reactor

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ABSTRACT

The BAEC TRIGA research reactor (BTRR) is the only nuclear reactor in Bangladesh. Bangladesh Atomic Energy Regulatory Authority (BAERA) regulations require that nuclear reactor licensees undertake all reasonable precautions to protect the environment and the health and safety of persons, including identifying, controlling and monitoring the release of nuclear substances to the environment. The primary activation product of interest in terms of airborne release from the reactor is ^{41}Ar. ^{41}Ar is a noble gas readily released from the reactor stacks and most has not decayed by the time it moves offsite with normal wind speed. Initially ^{41}Ar is produced from irradiation of dissolved air in the primary water which eventually transfers into the air in the reactor bay. In this study, the airborne radioisotope ^{41}Ar generation concentration, ground level concentration and release rate from the BTRR bay region are evaluated theoretically during the normal reactor operation condition by several governing equations. This theoretical calculation eventually minimizes the doubt about radiological safety to determine the radiation level for ^{41}Ar activity whether it is below the permissible limit or not. Results show that the estimated activity for ^{41}Ar is well below the maximum permissible concentration limit set by the regulatory body, which is an assurance for the reactor operating personnel and general public. Thus the analysis performed within this paper is so much effective in the sense of ensuring radiological safety for working personnel and the environment.

1. Introduction

Radioactive effluents released and wastes produced in a nuclear reactor or other nuclear industrial activities may result in a large variety of adverse environmental impacts causing damage to natural, physical and ecological resources and to people, economies and quality of life []. As effluents are dispersed, wind direction and atmospheric conditions such as temperature, quantity of solar radiation, and wind speed distinctly affect the transport pathway of any effluent traveling from the reactor building stack [Smith, 1979; Turner, 1973]. The main activity of noble gases produced by the research reactor consists of ^{41}Ar, which is produced by activation of air in cavities. Usually, other gases like fission products can be neglected under normal operational conditions because their appearance in the gaseous effluents is some orders of magnitude below the level of ^{41}Ar. The fission noble gases have to be considered only in the case of fuel element failure or in accidental conditions.

During normal reactor operation, the radioisotope ^{41}Ar is generated and released continuously to the environment. Radioactive ^{41}Ar quickly mixes with reactor building air and then releases via the airflow through the reactor stack. Once out the stack, radioactive gases moved with local air flows offsite, and individuals living nearby are potentially exposed to beta and gamma radiation emitted during ^{41}Ar decay. As the half-life of ^{41}Ar is relatively short compared to average characteristic atmospheric transport time scales, radiation exposures calculated for this radionuclide are highest near the site boundary, and decreased more rapidly than for most other radionuclides with distance from the site. In the reactor bay, ^{41}Ar is produced primarily from irradiation of dissolved air in the primary water which eventually transfers into the air in the reactor bay. This evolution can cause direct radiation exposure to the radiation workers and members of the public. ^{41}Ar is the principal activation product of interest in terms of atmospheric

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releases and when considering offsite human health risk. For this reason, it is important to evaluate the amount of ^{41}Ar release to keep dose to the workers and the members of the public below the acceptable limit. In the present study, the ^{41}Ar activity concentration and release rate have been calculated theoretically in normal reactor operational condition to meet the regulatory requirements and to ensure the safety of workers and the public.

2. Brief description of the BAEC TRIGA research reactor

The BAEC TRIGA Research Reactor achieved its first criticality on 14 September 1986. The reactor has been operating successfully since commissioning. 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. Fuel is composed of 20% (wt) Uranium enriched to 19.7% (the amount of ^{235}U isotope is 19.7%), Zirconium hydride ($ZrH_{1.6}$) and burnable poison Erbium (^{167}Er). The array also contains graphite elements, which serves to reflect neutrons back into the core. The core is situated near the bottom of water filled tank and the tank is surrounded by a concrete bio-shield. The tank 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 L of demineralized water. 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 [(Hosan et al., 2015; Salam et al., 2014)]. 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 is controlled by six control rods, which contain Boron Carbide (B_4C) as the neutron absorber material. Figs. 1 and 2 show the shield structure and core structure of the BTRR. The reactor is housed in a hall of 23.5 m × 20.12 m having a height of 17.4 m. The reactor hall exhaust is monitored by two separate pancake type GM (Geiger–Muller) detectors (one for particulate and another for noble gas monitor) provided with alarms for excessive radiation and instrument failure. The volume of the reactor hall is 8202.65m^3. There exists a reactor building ventilation system which purpose is to draw radioactive particulate and gases from different parts of the reactor building in order to discharge them into the atmosphere after proper filtering. Sample of the reactor hall effluent is continuously monitored by stack monitor. The effluent is discharged through the stack located at reactor building roof top having height 24.38 m. It is mandatory to operate the reactor hall ventilation system when the reactor is operating. Fig. 3 shows the cross-sectional view of the reactor shield structure. The reactor is licensed by the Bangladesh Atomic Energy Regulator Authority (BAEC Report, 2006) to operate at a maximum steady state power of 3 MW (thermal) and can also be pulsed up to a peak power of about 852 MW.

Fig. 1. Shield structure of the BTRR.

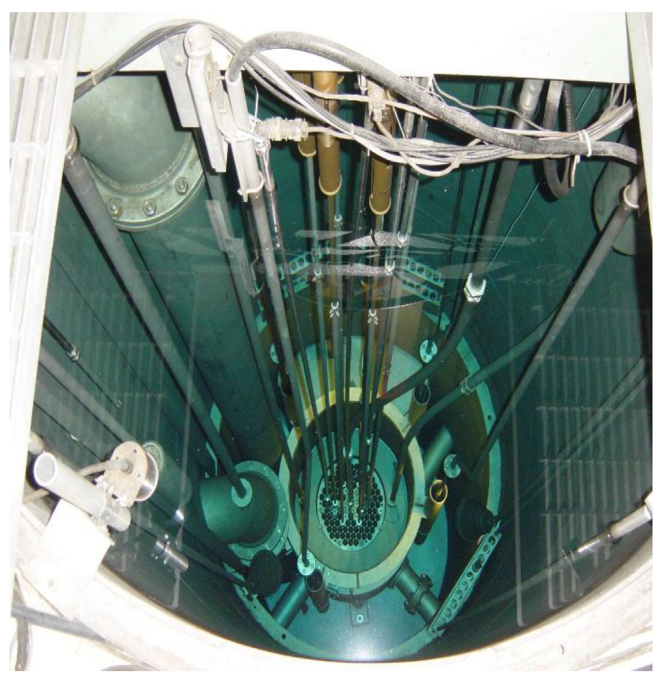

Fig. 2. Core structure of the BTRR.

3. Method of generation and calculation of ^{41}Ar

3.1. *Method of ^{41}Ar generation*

Argon, as a natural constituent in air, was discovered by Lord Raleigh and Sir William Ramsey in 1894, but was initially suspected to exist by Cavendish in 1785 (Los Alamos National Labs). ^{40}Ar is ~99.6% of this natural argon, which is ~1.3 weight percent, or about ~0.94 volume percent of air (Korean Atomic Energy Research Institute (KAERI),; U. S. Nuclear Regulatory Commission, 1873). Radioactive argon gas (^{41}Ar) is produced when naturally occurring ^{40}Ar captures a thermal neutron. ^{40}Ar is present throughout the air spaces surrounding the BTRR fuel. Eq. (1) shows the activation of ^{40}Ar. Note that the half-life of ^{41}Ar is 1.83 h.

$$n + {}^{40}\mathrm{Ar} = {}^{41}\mathrm{Ar} + \gamma \qquad (1)$$