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Study the effect of beryllium reflector poisoning on the Syrian MNSR

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ABSTRACT

Neutron interactions with beryllium lead to formation of ^{3}H and strong neutron absorbers ^{3}He and ^{6}Li in the reflector (so called beryllium poisoning). After the reactor shutdown, the concentration of ^{3}He increases in time due to tritium decay. This paper illustrates the impact of poisoning accumulation in the beryllium reflectors on reactivity for the Syrian MNSR research reactor. The prediction of ^{6}Li and ^{3}He poison concentrations, initiated by the $^{9}Be(n,\alpha)$ reaction, in the beryllium reflectors of the MNSR was also presented. The results were based on MCNP Monte Carlo calculations and solutions to the differential equations which describe the time dependent poison concentrations as a function of reactor operation time and shutdown periods. The whole reactor history was taken into account to predict reliable values of parasitic isotope concentrations. It was found that the ^{3}He and ^{6}Li accumulations in the beryllium reflectors during the actual working history decreased the excess reactivity by about 28%. While, the effect became more significant at the reactor life's end and the reactor became subcritical after 25,000 h operation. The results contained in this paper could be used in assess the safety analysis of the MNSR reactor.

1. Introduction

Beryllium has been widely used as a neutron reflector in the nuclear reactors due to its good reflection property, its additional neutrons contribution, and its unique combination of structural, chemical, atomic number, and neutron absorption cross-section characteristics. Besides, it has the advantage of reducing the critical mass (Glasstone and Sesonske, 1967). Beryllium has another type of reactions with gamma rays as (γ,n) reaction to produce photoneutrons. This is helpful in overcoming the instrumentation difficulty of 'blind zone' during reactor start-up after any shutdown (Knoll, 1989). However, it has a disadvantage when utilized since the residual power after shutdown is a little higher and the power decay time is also a little longer than that in normal water reactors without beryllium (Lamarsh, 1983). The collision of fast neutrons with beryllium atoms makes the energy transfer from neutrons to the atoms and cause the atoms to be displaced, which in turn destroys the crystal lattice and thereby changing the properties of the beryllium (Muhammad et al., 2008; Glasstone and Sesonske, 1967).

The main reaction between fast neutrons and beryllium atoms is $(n,2n)$, while the reaction (n,α) is also significant, contributing about 10%. The gases of ^{4}He, ^{3}He and ^{3}H produced in that reaction will be accumulated as burn-up increases. This would cause certain hazards like Be swelling, hardening or brittleness. At the same time, the accumulation of reaction products ^{6}Li and ^{3}He will increase neutron poisoning thus the reactivity with gradually decrease and override the benefits due to $(n,2n)$ and (γ,n) reactions (Renterghem et al., 2008). As a result, it is important to estimate the beryllium poisoning in the beryllium reflectors of the MNSR and due to the absence of experimental method, numerical techniques are used for its determination.

2. Reactor description

The Syrian Miniature Neutron Source Reactor (Syrian MNSR) is a low power research reactor (LPRR) of nominal power 30 kW. It is a small, safe nuclear facility which employs high enriched uranium as fuel, light water as moderator, coolant and shield and beryllium as reflector. The reactor is cooled by natural convection. The reactor is a tank-in pool type reactor. The reactor complex contains five major components. These are the reactor assembly, control console, auxiliary systems, irradiation system and the pool. The schematic diagram of the reactor is shown in Fig. 1. The reactor assembly consists of the reactor core, beryllium reflector, small fission chambers for detecting neutron fluxes, one central control rod and its drive mechanism, and thermocouples for measuring inlet and outlet temperatures of the coolant. There are five inner irradiation tubes installed within the beryllium annulus, five outer irradiation tubes are also installed outside the beryllium annuals. The reactor vessel is a cylindrical aluminum alloy container, 0.6 m in diameter and 5.6 m high. The container

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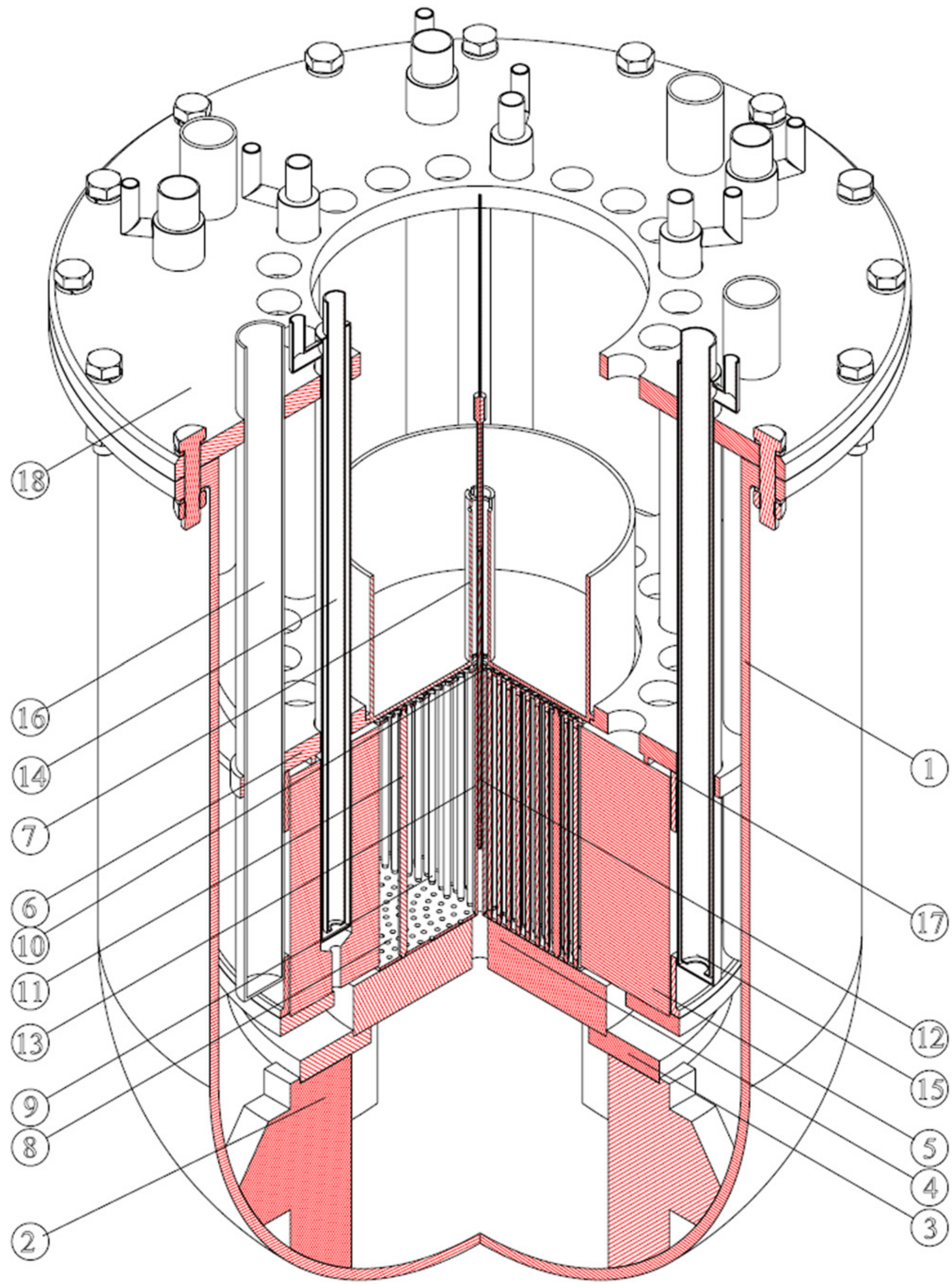

Fig. 1. MNSR isometric view; 1—reactor vessel, 2—reactor base, 3—lower orifice, 4—lower reflector, 5—annular reflector, 6—upper orifice, 7—upper shim tray, 8—lower grid plate, 9—fuel elements, 10—upper grid plate, 11—tie rod, 12—control rod, 13—control rod clad, 14—inner irradiation sites, 15—outer irradiation sites, 16—reactivity regulator, 17—core cover, 18—vessel cover.

which is built in two sections is suspended in a stainless steel-lined water pool made of reinforced concrete.

The core consists of fuel elements which form a fuel cage. The cage is inside an annular beryllium reflector and rests on a lower beryllium reflector plate. The volume of the vessel is 1.5 m^3. The fuel elements are all enriched uranium–aluminum alloy extraction clad with aluminum. They are arranged in ten multi-concentric circle layers at a pitch distance of 10.95 mm. The element cage consists of two grid plates, four tie rods and a guide tube for the control rod. The two grid plates and four tie rods are connected by screws. The total number of lattice positions is 350 and the number of fuel elements is 347. The remaining positions are filled with dummy aluminum elements.

The beryllium annulus and lower reflector are spaced to form the lower orifice which controls water flow through the core. The top plate of the core and annulus are spaced to form the upper orifice. The reactor core is cooled by natural convection. An aluminum tray holds the upper reflector which contains semi-circular beryllium shims which are added approximately once a year to compensate for fuel burn-up and samarium poisoning.

After operating the reactor for a period of 2.5 h at the rated power, the reactor will be shut down because of Xe poisoning and can only restart after Xe decay. Under the condition of maximum flux of 1×10^{12} n/cm^2 s in the inner experimental tube, the cold excess reactivity of 390 pcm (1 pcm = 0.00001 $\Delta k/k$) and initial core temperature of 15.8 °C, the maximum operated time is about