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Utilization of high-density fuel and beryllium elements for the neutron flux enhancement in typical MTR type research reactors

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Abstract

Pakistan Research Reactor-1 (PARR-1) is a typical MTR type swimming pool reactor utilizing low enriched uranium (LEU), i.e. 19.99% enriched in ^{235}U, silicide dispersion fuel of density 3.28 gU/cm^3. This simulation study was conducted by employing the standard reactor physics simulation codes WIMS-D/4, CITATION, and a burnup analysis code FCAP along with a reactor thermal hydraulic simulation code PARET. The present study shows that by directly substituting LEU silicide dispersion fuel of density 4.8 gU/cm^3 in place of fuel currently in use in PARR-1 and by loading beryllium elements at the unused 9×6 position of PARR-1 grid plate, a smaller equilibrium core can be designed that can provide 82% higher neutron fluxes at the central flux trap position at 14% lower cost than the existing core. Fuel cycle length of this core is also two days larger than the existing core and this core can be operated safely at the existing power of 10 MW with the existing coolant flow rate of 1000 m^3/h. A possible use of LEU U–Mo monolithic fuel of density 15.3 gU/cm^3 with some adjustment in fuel to moderator ratio and use of Be reflector would provide 89% higher neutron flux in PARR-1 at 29% lower cost. Fuel cycle length of this core will be five days shorter than the existing core and it will require 48% more coolant flow rate for its safe operation at 10 MW.

Keywords: Reactivity; Fuel loading; Performance

1. Introduction

High-density LEU fuels are being developed for the conversion of a large number of research reactors' highly enriched uranium (HEU) cores around the world into low enriched uranium (LEU) cores (Travelli, 2004). Highest density fuel developed up till now for research reactors is based on U_3Si_2–Al with densities up to 4.8 gU/cm^3 and the highest density fuel being developed for research reactors is LEU U–Mo monolithic fuel of density about 15.6 gU/cm^3 (Travelli, 2003, 2004).

High neutron fluxes are always desired in research reactors for the efficient irradiation of samples. By increasing the power density in a core, neutron fluxes at the irradiation sites of a core can be increased. Power density can be increased in a core by increasing the core power or/and by reducing the core size. Power upgradation requires changes in the thermal hydraulic system and also increases dose rates at various core sites (Khan et al., 1992). Reduction in the core size by means of reduction in the number of fuel elements in the core reduces the overall heat transfer area in the

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core. But, the adverse effect on the core thermal hydraulics due to reduction in the heat transfer area is almost compensated by the increased coolant flow rate per fuel element provided the number of fuel plates in the fuel elements and coolant flow rate through the core remain unchanged (Ahmed et al., 2005a). The small adverse effect on the core thermal hydraulics due to reduction in core size can be managed by reducing the power peaking factors in the compact core through better fuel management.

Reduction in the size of a core reduces the fuel loading and increases the neutron leakage and hence affects the overall fuel economy of the core. High-density fuels can be utilized to achieve higher fuel loading in a small core and neutron leakages from the core can be reduced by reflecting the core with suitable reflecting material. Beryllium is the best reflecting material and it can give better performance than any other reflector material (Ahmad et al., 2005b). However, replacement of low-density fuel by a high-density fuel may also require an increase in the water/coolant channel width for better results (Ahmed et al., 2005a).

Pakistan Research Reactor-1 (PARR-1) is an MTR type swimming pool reactor and was converted in 1992 from HEU to LEU fuel by utilizing silicide dispersion fuel of density 3.28 gU/cm^3. The reactor power was also upgraded at the time of core conversion from 5 to 10 MW. In this study, we have enhanced PARR-1 performance by directly loading LEU silicide dispersion fuel of density 4.8 gU/cm^3 in PARR-1 core and beryllium elements at the unused 9×6 positions of the PARR-1 grid plate. Effect of loading LEU U–Mo monolithic fuel of density 15.3 gU/cm^3 in PARR-1 core along with an increase in the coolant channel width from existing 2.1 to 3.0 mm and partial replacement of water reflector around the core by means of loading beryllium elements at the unused 9×6 positions of the PARR-1 grid plate was also analysed on PARR-1 performance. Objective of this study was to enhance neutron fluxes for irradiation in PARR-1 under the following constraints.

(i) No modifications can be made in the fuel element dimensions (i.e. fuel meat thickness, clad thickness, etc.).
(ii) All the irradiation facilities must remain intact and the neutron flux at none of these facilities should reduce.
(iii) Sufficient one stuck rod shut down reactivity must be maintained.
(iv) Fuel cycle length of the cores should be comparable to that of existing PARR-1 core.

2. Materials and method

2.1. Reactor core assembly

PARR-1 core is an assembly of standard and control fuel elements on a grid plate. The grid plate has 54 holes in a 9×6 pattern with a lattice spacing of 81.0×77.1 mm. The core is immersed in either one of the two sections of the swimming pool filled with demineralized light water, which acts as coolant, moderator, and reflector. These two sections of the swimming pool are called stall-end and open-end. When the core is at stall-end, it is reflected by a graphite thermal column on one side and by light water from all other sides. At open-end, the core is reflected from all the sides by light water. However, light water reflector can be replaced on one or more sides with other reflectors such as graphite or beryllium using specially designed reflector elements (Khan et al., 1992). PARR-1 core and fuel design parameters and other details may be seen in our recently published work (Ahmed et al., 2005a,b; Ahmad et al., 2004, 2005a,b).

2.2. Methodology and computer codes used

The LEU silicide dispersion fuel of density 3.28 gU/cm^3 being used in the fuel elements of PARR-1 was directly replaced with the same type fuel of density 4.8 gU/cm^3 and a new equilibrium core comprising 13 fuel elements (nine standard fuel elements (SFEs) and four control fuel elements (CFEs) will be called core A in the remaining text of this article) was searched. A further reduced size core comprising only 10 fuel elements (six SFEs and four CFEs will be called core B in the remaining text of this article) was searched by replacing the existing fuel of density 3.28 gU/cm^3 with the U–Mo monolithic fuel of density 15.3 gU/cm^3 and by increasing the water/coolant channel width from existing 2.1 to 3.0 mm. This increase in the water/coolant channel width reduced the number of fuel plates in the SFE from 23 to 18 and from 13 to nine in the CFE. In case of cores A and B, beryllium elements were also loaded at the unused 9×6 positions of PARR-1 grid plate. Configuration of the existing core, cores A and B can be seen in