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Sensitivity analyses of the use of different reflector materials on the neutronics parameters of Tehran research reactor

Farrokh Khoshahval [a,*], Farhad Salari [b]

[a] Reactor Research and Development School, Nuclear Science and Technology Research Institute (NSTRI), Tehran, 143995-1113, Iran
[b] Faculty of Electrical and Computer Engineering, Kerman Graduate University of Technology, Kerman, Iran

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ABSTRACT

In this paper, the effect of changes in neutron reflector type on neutronics parameters of Tehran research reactor is analyzed. In this study, at first, calculations for the HEU and LEU fuel configurations of the reactor core in which the light water is used as a neutron reflector in the core is done. Then, by using the reflectors such as graphite, beryllium and heavy water, changes on the neutronic parameters are examined. The results show that by altering the reflector, at HEU core configuration (compared with LEU), more changes appear in parameters such as neutron multiplication factor, average fast and thermal neutron flux, excess reactivity and shut down margin. Moreover, at LEU core configuration, changes are tangible specifically on parameters of cycle length and power peaking factor. In addition, the evaluated fuel temperature coefficient of reactivity is greater at HEU than LEU, while the temperature alteration of fuels represented greater influence on reactivity at LEU configuration.

1. Introduction

In nuclear research reactors, neutron reflectors with a variety of different materials are used in the reactor core.

Advantages of using reflectors in the reactors core are presented as follows:

1) To reduce the critical size of the core and reactor
2) To reduce the critical mass of the fuel
3) To flatten the neutron flux and power distribution.

Reflectors require the same characteristics that moderators have: a small atomic weight, a high scattering cross section, a high slowing-down power, and a low absorption cross section (Albarhoum, 2011). Table 1 shows some reflectors with their moderating characteristics.

In the first core configuration of TRR (HEU core configurations), light water used as reflector.

In the design of reactor fuel conversion from HEU to LEU, light water reflector was utilized in the LEU configurations as well. In current and proceeding configurations several aluminum boxes containing graphite are used in the reactor core.

Changing reflector materials of the reactors core largely affects some of the safety or neutronic parameters of the reactor core. Several studies have been done on the influence of reflector changes on these parameters (Albarhoum, 2011, 2012; Dawahra et al., 2015a,b). Also in other studies, the effect of changes in the reflector thickness or its purity has been addressed (Odoi et al., 2011; Khattab and Khamis, 2007).

To analyze the effect of reflector types on the neutronic parameters, a 5 MW nuclear research reactor MTR type has been studied in this paper. Neutronic parameters which are evaluated here include neutron multiplication factor, average thermal and fast neutron flux, average power distribution of the core, power peaking factor, fuel cycle length, excess reactivity, core shutdown margin and temperature coefficient of reactivity.

To model and analyze the reactor in the neutronic view point, 3D neutronic models are developed using the WIMSD4 and CITATION codes. The WIMSD4 code is used to generate the group constants (cross-sections) for the standard fuel element, control fuel element, graphite, beryllium, heavy water, and light water. The CITATION code is then used to calculate the neutronic parameters

* Corresponding author. Reactor Research and Development School, Nuclear Science and Technology Research Institute (NSTRI), Tehran, 143995-1113, Iran.
E-mail address: f_khoshahval@sbu.ac.ir (F. Khoshahval).

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Table 1
Characteristics of selected reflectors (Albarhoum, 2011).

Parameters	H2O	D2O	Be	Graphite
Atomic weight	18.0	20.0	9.0	12.0
Density (g/cm^3)	1.0	1.10	1.84	1.57
Macroscopic scattering cross section (epithermal) (cm^{-1})	1.64	0.35	0.74	0.39
Macroscopic absorption cross section (thermal) (cm^{-1})	2.2E^{-2}	8.5E^{-5}	1.1E^{-3}	3.7E^{-4}
Average number of collision to thermalize,	19.6	35.7	88.4	115
Slowing down power (cm^{-1})				
Moderation ratio	70	12	150	170

mentioned above in the reactor using two energy groups.

The use of the reflectors in the core reduces the amount of fuel needed for criticality, by decreasing the leakage of neutron from the core and this is an important problem now a day, because of the high cost of fuel manufacturing and enrichment. Moreover, reflectors improve the burn up levels between the cells and make them very near to each other. Also the maximum temperature which is high in the center of the bare$\upsilon\sum_f$), diffusion coefficient (D), the scattering matrix ($\sum_{s,g\rightarrow g'}$) and the fission spectrum for all groups, as input data. At first, all elements used in the reactor core for the group constants generation should be individually simulated using WIMS-D4 code. These group constants are required as input for the 3-D reactor calculation using one of the diffusion codes such as CITATION code. The core configuration is modeled using CITATION code for core parameters calculation (by defining characteristic of the different regions of the core).

2. Description of TRR

TRR is a 5 MW, pool-type light-water moderated, heterogeneous solid fuel reactor in which the water is also used for cooling and shielding. Its core configuration contains MTR-type fuel elements that are arranged in 9×6 grid plate assembly. Reactor general description is summarized in Table 2. This reactor became critical using HEU fuel that was more than 90% enriched in ^{235}U, in 1967. In 1992, the new LEU fuel, containing less than 20% enrichment in ^{235}U, was used. The reactor core consists of three types of fuel elements: SFE (standard fuel element), CFE (control fuel element) and PFE (partial fuel element). TRR with HEU fuel consisted of 22 SFE, 6 CFE and 2 PFE and with LEU fuel consisted of 24 SFE and 5 CFE. Other details of LEU and HEU fuel assemblies and core parameters are given in TRR-Safety Analysis Reports (SAR) (AEOI, 1966; AEOI, 2001). Specifications of TRR fuel assemblies (HEU and LEU) are given in Table 3. It is notable that, thespecifications of PFE fuel are exactly the same as SFE specifications at HEU configuration, only with the difference in thenumber of fuel plates (half of HEU-SFE), which their specifications are ignored in Table 3.

The cross-sectional views of TRR fuel assemblies for HEU (HEU-SFE and HEU-CFE) and LEU (LEU-SFE and LEU-CFE) are shown in Figs. 1 and 2 respectively. It is worth mentioning that, although the current fuel of TRR is LEU, but in order to see the effect of fuel type on the results of selecting different reflector, we assess HEU fuels too.

3. Methodology

3.1. Theoretical modeling

Neutronic codes WIMS-D4 (Hallsall, 1980) and CITATION (Fowler et al., 1971) are the main tools used in this research. The WIMS-D4 code is used for the generation of group constants for various core regions while CITATION is used to perform global core calculations. The CITATION code needs macroscopic absorption cross section ($\sum_a$), Production cross-section ($\upsilon\sum_f$), diffusion coefficient (D), the scattering matrix ($\sum_{s,g\rightarrow g'}$) and the fission spectrum for all groups, as input data. At first, all elements used in the reactor core forthe group constants generation should be individually simulated usingWIMS-D4 code.These group constants are required as input for the 3-D reactor calculation using one of the diffusion codes such as CITATION code. The core configuration is modeled using CITATION code for core parameters calculation (bydefining characteristic of the different regions of the core).

3.2. Planar modeling of SFE and CFE

Fig. 3 shows SFE model which is divided into three separate regions in xy-plane for HEU (Fig. 3a) and LEU (Fig. 3b). In both Figures (Fig. 3a and b), one region (region 1) represents the fueled

Table 2
Reactor general description of TRR.

Parameter	Value
Type	Open pool, water
Design	AMF, USA
Thermal power	5 MW
Original fuel	High enriched uranium (HEU) More than 90% (U—Al) Alloy
Present fuel	Low enriched uranium (LEU) 20% U_3O_8
Cooling system	Forced flow
Coolant	Light water
Moderator and coolant	Light water
Reflector	Light water (HEU)
SFE dimension	Light Water— Graphite (LEU)
Primary coolant flow rate	500 m3/h
Secondary coolant flow	522 m3/h
Coolant inlet temperature in 5 MW	37.8° C
Coolant outlet temperature in 5 MW	46° C
Safety rods absorber	Ag: 80% In: 15% Cd: 5%
Regulating rod absorber	AISI-316L stainless steel