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Reactivity coefficients simulation of the Iranian VVER-1000 nuclear reactor using WIMS and CITATION codes

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Abstract

Reactivity coefficients analysis of the Bushehr Nuclear Power Plant (BNPP), VVER-1000, at nominal conditions is carried out during its first operational cycle where we used WIMS and CITATION codes in our theoretical studies. Modelling of all rods (including fuel rods, control rods, burnable and non-burnable poison rods) and channels (including central guiding channel, central channel and reactor perimeters) is carried out using the WIMS code. Moreover, modelling of the fuel assemblies and reactor core is completed using the CITATION code. The multi-group constants generated by WIMS for different fuel configurations are fed into CITATION. The multi-group constants for fuel assemblies are obtained from the flux distribution calculated by the code. Then by putting fuel assemblies together to make up the core, and using the calculated constants, the core multiplication factor is calculated for different conditions. A FORTRAN 90 program is written to link the WIMS and CITATION codes and facilitate their numerous executions. Our calculated reactivity coefficients are comparable with the plant's FSAR.

Keywords: BNPP; Simulation; Reactivity coefficients; VVER-1000; WIMS; CITATION

1. Introduction

Studies on the reactivity coefficients of a nuclear power plant are an important key for increased reliability and performance during its operational cycles. The reactivity coefficient of the Bushehr Nuclear Power Plant (BNNP), a VVER-1000 Russian model, was simulated during the first plant operational period using WIMS and CITATION codes (e.g., Ahmad et al., 2006). The Bushehr Nuclear Power Plant (BNPP) is currently under construction and will be loaded with 126 tons, up to 3.6% enriched fuel, having three years of life cycle (Hadad and Ayoubian, 2006). The purpose of this article is to analyze the criticality of BNPP at various reactor core conditions, while the excess reactivity of the core at nominal conditions with and without boric acid injected to the primary loop. The parameters of interest in this analysis are very important in design, control and safety. Following the calculations, the results are discussed and compared with the design limitation (Atomic Energy Organization of Iran, 2003) for

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those parameters which are key to the safe performance of the reactor. First, in the present work, we will illustrate and define rod, fuel assemblies, and core modelling of the plant. Then, in the following sections, boric acid and temperature reactivity coefficients are calculated for some of the operating conditions. The reactivity effects due to core material changes and isotopes produced during reactor operation are also studied.

2. Reactor modelling

2.1. Rods modelling

In the present study, all rods in the core are divided into 15 types so that from their different possible configurations, 10 fuel type assemblies are made and simulated. Fuel rods of different enrichments, burnable rods, central rods, cooling rods, material densities and other required information of the WIMS input files (United Kingdom Atomic Energy Authority, 1998) are listed in Table 1. WIMS has been extensively used for core calculations and effective cross-section computations (Bogado Leite, 2000). WIMS input data include structure of the following mentioned rods, as well as its shapes, enrichments, and dimensions. Since WIMS input cells were defined in cylindrical geometry and VVER-1000 had a hexagonal cell shape, we used the following formula to approximate hexagonal geometry with cylindrical one:

$$b = \frac{a}{2} \times \sqrt{\frac{2\sqrt{3}}{\pi}} \tag{1}$$

where b and a are the cylinder radius and hexagonal VVER cell pitch, respectively. The area of the hexagonal is approximated to a cylinder in Eq. (1). To calculate the ANNULUS and ARRAYS' radii, it is required that n hexagonal is assumed to be equivalent to a cylinder as shown in Fig. 1:

$$b = \frac{a}{2} \times \sqrt{\frac{2n\sqrt{3}}{\pi}} \tag{2}$$

As previously mentioned, the WIMS code is executed to find rod cross-sections for different cases. For instance, temperature, power, and boron variations may change rod cross-sections. Cross-sections will be tabulated under two different energy groups, "thermal" and "fast" by the ZADOC input card of the WIMS code. The results are fission ($\nu\Sigma_f$), scattering (Σ_s), absorption (Σ_a) macroscopic cross-sections, and also diffusion constant (D).

Table 1
All possible core rods of the BNPP VVER-1000 reactor

No.	Cell type	Description[a]
1	*Fuel*16	Fuel rods of 1.6% enrichment
2	*Fuel*24	Fuel rods of 2.4% enrichment
3	*Fuel*33	Fuel rods of 3.3% enrichment
4	*Fuel*37	Fuel rods of 3.7% enrichment
5	*BA*24 − 020	Burnable absorber rod used in 24B20 fuel assemblies
6	*BA*24 − 036	Burnable absorber pin used in 24B36 fuel assemblies
7	*GT*	Guide tube cell
8	*BT*	Bottom and top reflector cell
9	*LAT*	Lateral reflector cell around the core region
10	*CGT*	Central guide tube
11	*MGT*	Measuring guide tube
12	*Water hole*	Water + spacing grid around fuel assembly
13	*BA*36 − 036	Burnable absorber rod used in 36B36 fuel assembly
14	*DyTi*	CPS rod, dyspersium + titanate oxide part
15	*B4C*	CPS rod, boron carbide

[a] More descriptions of fuel assemblies' (FAs) abbreviation will be introduced in Section 2.2.