Improvements in the Determination of Reactivity Coefficients of PARR-1 Reactor

R. Khan[1*], Muhammad Rizwan Ali[1], F. Qayyum[1], T. Stummer[2]
1. DNE, Pakistan Institute of Engineering and Applied Sciences (PIEAS), Islamabad, Pakistan
2. Atominstitut, Vienna University of Technology, Vienna, Austria

ABSTRACT

The temperature change in fuel (or moderator changes the reactivity of the core as feedback. These feedbacks are characterized by reactivity coefficients. The accurate determination of reactivity coefficients is very important in reactor design and safety because of their significant influence on the reactor safety and stability. Conventionally, the Fuel Temperature Coefficient (FTC) is determined by estimating the reactivity change due to fuel temperature only whereas the change in fuel temperature also causes the change in moderator temperature. This associated (or coupled) effect of moderator temperature with fuel temperature is ignored in FTC calculation. The incorporation of moderator temperature effect associated with fuel temperature improves the overall FTC. Similarly, the determination of moderator temperature and void coefficient of the PARR-1 can also be improved. This paper emphasizes the improvements in the determination of reactivity coefficients of Pakistan Research Reactor -1 (PARR-1) employed with 19.99% LEU Uranium Silicide (U3Si2-Al) fuel. For this purpose, a detailed 3D model of the First High Power Core (FHPC) of PARR-1 reactor is developed using Monte Carlo N-Particle MCNP5 computer code and verified against the reference results. The validated model is applied to simulate the independent FTC (i.e. by taking the effect of fuel temperature only on the core) and associated coupling effect on moderator temperature to calculate the improved FTC of PARR-1 using the temperature dependent nuclear data library JEFF3.1.

1. Introduction

The nuclear reactor core reactivity depends on fuel type, enrichment, core fuel loading, amount of poison and temperature of fuel and moderator regions etc. The temperature of fuel and moderator regions are continuously changed during the reactor operation. It is known that an increase in fuel temperature causes Doppler effect, which is the most important and inherent shutdown mechanism that helps to assure the safety of nuclear reactors [1]. The individual effect of temperature change of different regions on reactivity is quantitatively different. Therefore, to quantify the effect of these parameters on reactivity, the reactivity coefficients are determined. Conventionally, the reactivity coefficients are calculated independently and there seems to be a specific inaccuracy in their calculations due to the neglecting the effect of one parameter on the other, e.g. in the determination of void coefficient of reactivity, change in coolant void in moderator region also causes spectral changes in fuel region.

This paper emphasizes the improvements in the determination of reactivity coefficients of Pakistan Research Reactor -1 (PARR-1) employed with 19.99% LEU Uranium Silicide (U3Si2-Al) fuel. For this purpose, a detailed 3D model of the First High Power Core (FHPC) of PARR-1 reactor is developed using Monte Carlo N-Particle MCNP5 computer code and verified against the reference results [2]. The validated model is applied to simulate the independent FTC (i.e. by taking the effect of fuel temperature only on the core) and associated coupling effect on moderator temperature to calculate the improved FTC of PARR-1 using the temperature dependent nuclear data library JEFF3.1.

2. Pakistan research reactor-1 (PARR-1)

PARR-1 is a 10 MWth swimming pool type research reactor. Initially it was designed to operate at 5 MW with HEU fuel. Later in 1992, it was converted to operate LEU fuel having an enrichment of 19.99% and its power was increased to 9 MW, which is then increased to 10 MW in 1998. The fuel used in PARR-1 reactor core is U_3Si_2-Al. Demineralized light water acts as a moderator, coolant as well as reflector [3]. The First High Power Core consists of 17 standard fuel elements (SFEs) and 5 control fuel elements (CFEs). It is a parallelepiped core is loaded with plate type fuel. One side of the parallelepiped core is reflected by graphite, i.e. thermal column, while opposite side is reflected by light water. There is thermal shield along with thermal column and lead shield. At PARR-1 reactor core, five (Ag-In-Cd alloy) control rods are employed for start-up, shutdown and reactor operating power level control [4]. Table 1 lists the design parameters of PARR – I fuel.

Table 1: Description of PARR – I fuel parameters [8].

Parameter	Description
No. of Fuel Plates	
Standard Fuel Element	23
Control Fuel Element	13
Thickness of the Plates (*mm*):	
Inner Plates	1.27
Outer Plates	1.50
Fuel Meat Dimensions (*mm*):	
Length	600
Width	62.75
Thickness	0.51
U^{235} Contents (*g*):	
Standard Fuel Element	290
Control Fuel Element	164
Fuel Plate	12.61
Uranium density in Fuel Meat (*g*/*cc*)	3.325
U-235 density in Fuel Meat (*g*/*cc*)	0.657
Water Channel Thickness (*mm*)	2.10

3. Computer Model of PARR-1 Reactor core

Monte **C**arlo **N**-**P**article (MCNP) is a general-purpose Monte Carlo based stochastic computer code. MCNP solves particle transport problem therefore it can be used for the transport neutron, photon, and electron separately, or coupled neutron/photon/electron transport [10]. Its capability to calculate eigenvalues for critical systems is exploited in this work. Rather than energy groups (as in deterministic techniques), MCNP uses a continuous energy concept with point-wise cross-section data [5]. The neutron energy ranges from 10-11 MeV to 20 MeV. MCNP has detailed tally capabilities e.g. neutron flux, fission energy, dose calculations can easily be performed [5].

A detailed three dimensional model of the PARR-1 reactor core is developed and verified against the reference results as published in [2]. The model employs the FHPC core which includes 17 standard fuel elements (SFEs), 5 control fuel elements (CFEs), water reflector and thermal column as shown in Figure 1 [2].

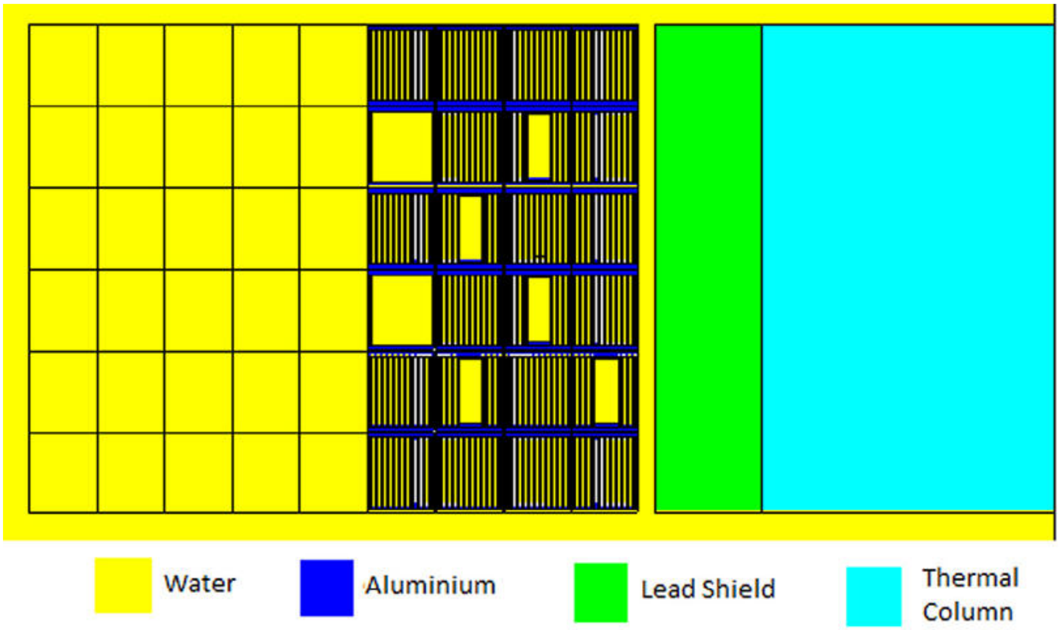

Figure 1: Cross-sectional view of FHPC modeled in MCNP [2].

4. Results and Discussion

Reactivity Coefficient

Reactivity coefficients quantify the amount that the reactivity will change for a given change in the parameter. For instance, an increase in moderator temperature may cause a decrease in the reactivity of the core. Typical units for the temperature coefficient are pcm per degree temperature [7]. In this work Fuel and Moderator temperature coefficient are determined.

Fuel Temperature coefficient

It is the change in reactivity per unit change in fuel temperature [8]. It is calculated by varying fuel temperature with an increment of 50 oC (or 50 K) and determining respective reactivity. The results are given in Table 1. With an increase in temperature the reactivity is decreasing but the FTC is almost constant. This can also be seen in Figure 2.

Table 2: Fuel temperature coefficient of PARR-I

Temperature (^oC)	Reactivity (pcm)	ΔT	FTC (pcm/^oC)
27	-60		
77	-160	50	-2.00
127	-251	100	-1.91
177	-352	150	-1.95
227	-439	200	-1.89
327	-636	300	-1.92
427	-810	400	-1.87

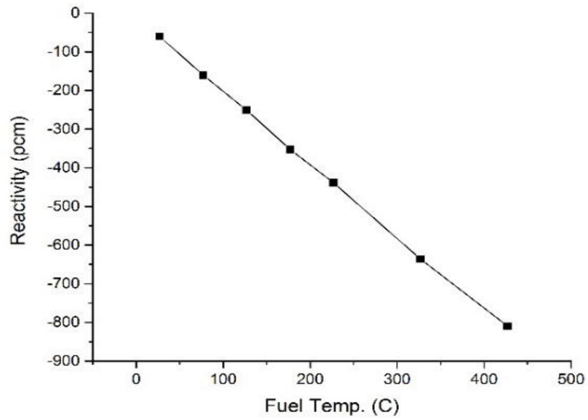

Figure 2: Reactivity as a function of fuel temperature.

Moderator Temperature Coefficient (MTC)

MTC is the change in reactivity per unit change in moderator temperature. It is calculated by varying moderator temperature with an increment of 20 ^{o}C (20 K) and determining respective reactivity. The results are given in Table 2. It is clear from the results that with an increase in moderator temperature MTC becomes more and more negative. This is inherent safety feature of light water moderated reactors. Figure 3 shows the variation of reactivity with moderator temperature.

Table 3: Reactivity as a function of moderator temperature

Temperature (^{o}C)	Reactivity (pcm)	ΔT	MTC (pcm/^{o}C)
27	-60.04		
40	-192.37	13	-10.18
60	-498.47	33	-13.29
80	-947.90	53	-16.75
100	-1415.76	73	-18.57
120	-1980.46	93	-20.65
140	-2554.64	113	-22.08

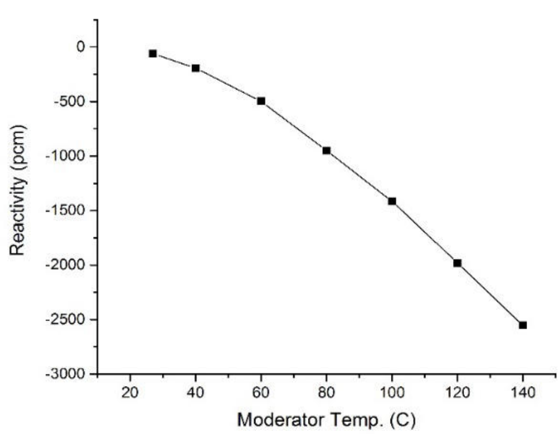

Figure 3: Moderator temperature coefficient of FHPC

Coupling of Fuel Temperature Coefficient

For the coupling of fuel temperature and moderator temperature reactivity coefficients, first the fuel temperature and moderator temperature coefficient of reactivity are determined independently. Using the Taylor series expansions, the coupling of the FTC and MTC is determined [4]. The uncoupled and coupled FTC are calculated at three different fuel temperatures i.e. 300 K, 400 K and 500 K for three different moderator temperatures i.e. 313 K, 333 K and 353 K. Similarly, the uncoupled and coupled MTC are calculated at three different moderator temperatures i.e. 333 K, 353 K, 373 K and for three different fuel temperatures i.e. 300 K, 400 K and 500 K.

For fuel temperature change of 100 K and moderator temperature change of 20 K, the improvements achieved in FTC and MTC are 4.86% and 1.79% respectively. There is slight improvement in reactivity feedback coefficients by taking account of change in moderator temperature on fuel temperature coefficient and vice versa.

5. Conclusion

The results show that that the fuel reactivity coefficient with coupled spectral effects is more accurate than the coefficient without spectral coupling. Similarly improvements in moderator and void coefficient of the PARR-1 reactor core can be studied. The improvements in reactivity coefficients can be applied to improve the research reactor design and hence safety parameters.

6. References

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