MONTE CALRLO MODELLING OF VOID COEFFICIENT OF REACTIVITY EXPERIMENT

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ABSTRACT

The Atominstitute (ATI) of the Vienna University of Technology utilizes a TRIGA Mark II research reactor for last fourty eight years at a nominal reactor power of 250 kW (thermal). It has a completely mixed core and employing three different types of fuels i.e. aluminium clad fuel with 20% enrichment, stainless steel (SS) clad fuel with 20% enrichment and SS clad FLIP fuel with 70% enrichment. The current core loading is 83 fuel elements. The reactor core is equipped with many irradiation facilities inside the core to irradiate samples at different flux levels. These irradiation facilities include the Central Channel (CC which is used to irradiate samples at maximum flux. This paper presents the calculations and measurements of the void coefficient of reactivity in CC. For this purpose, a cylindrical void of 66.47 cm^3 was inserted into the CC and moved from bottom to top of the core along the axial length of the channel in steps of 5 cm. For each step, the effect of void sample on the core reactivity was measured by the regulating control rod position. This experiment was performed at 10W in automatic mode of operation.
Monte Carlo neutronics simulating code, equipped with the cross sections library JEFF 3.1, was employed to perform these calculations. For each 5 cm step in the central irradiation channel, a separate model was executed. To see the influence of the control rods, the MCNP calculations were performed. In theses calculations, the control rods were set to the reactor operating conditions. Both the simulated and measured results were compared. Fairly good agreement was observed between calculations and experimental results.

1. Introduction

The Atominstitute (ATI) of Vienna University of Technology utilizes the TRIGA Mark II research reactor for its research, training and educational interests for last 48 years. The reactor operates at an average power level of 250kW and is equipped with many irradiation facilities inside and outside the reactor core. Inside the core, there are many irradiation channels including central thimble CC which is used for high flux irradiation. Starting with 57 Fuel Elements (FE(s)) of same type in 1962, the current core has 83 FE(s) of three different types. Out of 83 FE(s), 54 are 102-type (Aluminium-clad, 20% enriched), 20 are 104-type (Stainless Steel-clad, 20% enriched) and 9 are FLIP (SS-clad, 70% enriched) FE(s). These FE(s) are cylindrical in geometry and are arranged into 5 concentric circles (rings) in an annular lattice [1]. The schematic diagram of TRIGA FE is shown in Figure 1[2].

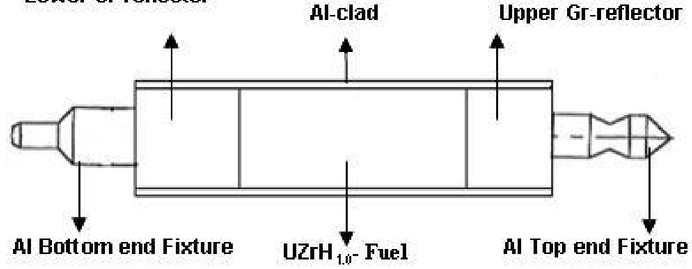

Fig 1. Schematic diagram of TRIGA Mark II reactor fuel element [2].

The reactor utilizes zirconium hydride fuel which is a homogeneous mixture of uranium (U) and zirconium hydride (ZrH). The ZrH is used as main moderator. About 80% of the neutron moderation occurs inside the fuel. Since the moderator has the special property of moderating less efficiently at high temperatures, the TRIGA reactor can produce a pulse of 250 MW for roughly 40 milliseconds [1].

The operational safety of the reactor needs the information of reactivity effects on the core caused by small disturbances. To investigate the void effect on the core reactivity, this work focuses on the calculation of the void coefficient of reactivity and its experimental confirmation in the central irradiation channel CC. The current core map including in-core irradiation facilities is shown in Figure 2.

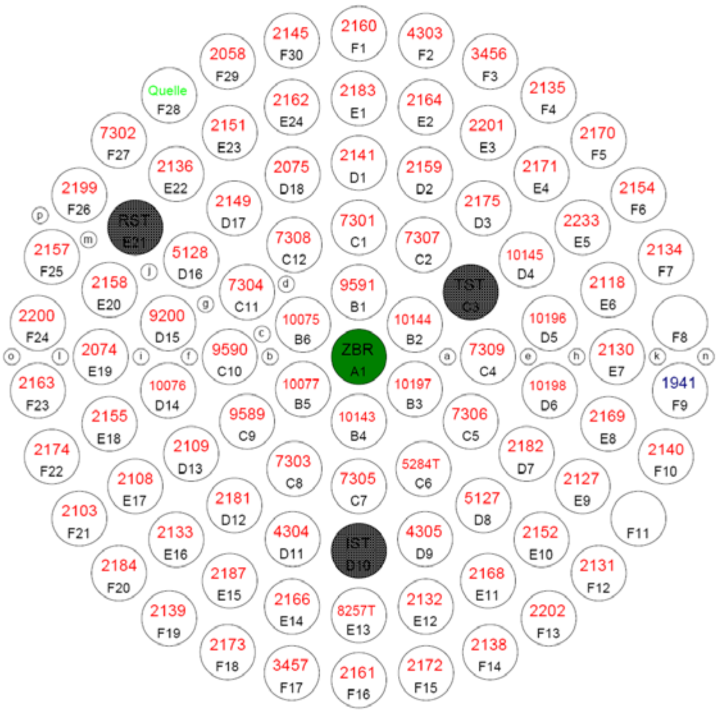

Fig 2. The current core map of the TRIGA Mark II research reactor.

1.1 Void Coefficient of Reactivity

The dominant reactivity effect in water moderated reactors arises from the changes in moderator density, due to either thermal expansion or void formation. The principal effect is usually the loss of moderation that accompanies a decrease in moderator density and causes corresponding increase in resonances [5]. In contrast with water moderated reactors, about 80% of the moderation occurs inside the fuel of TRIGA reactors. Therefore void effects on core reactivity of TRIGA reactor is studied in the paper.

Core reactivity, for given value of K_{eff} is determined by the relation [3]

$$\rho = \frac{K_{eff} - 1}{K_{eff}} \tag{1}$$

Generally the reactivity coefficient is defined as the change in reactivity for a given change in parameter [4]. Mathematically written as

$$\gamma_{\xi} = \frac{\Delta \rho}{\Delta \xi} \tag{2}$$

Here ξ is reactor parameter that affects reactivity and $\Delta\rho$ is the corresponding change in reactivity. If the ξ represent void (or V_D) then γ_ξ defines the void coefficient of reactivity [3]. The actual value varies from reactor to reactor. In this work, the effect of a void (in CC) on the TRIGA core reactivity is studied.

2. Measurements: Void Coefficient Experiment

This experiment was performed at ATI reactor at 10W reactor power. The reactor control was set to automatic mode and the regulating rod was selected as the only reactivity controlling variable for this experiment. The regulating control rod was selected because it is capable of achieving a finer control of the core as compared to the other two control rods. The 66.47 cm^3 void sample in an airtight cylindrical polyethylene bottle of length 10.8 and a radius of 1.4 cm was prepared at ATI. This sample holder was attached to a string and inserted into CC. The sample was first placed at the bottom of the core and then raised in 5 cm steps along the axial length of CC. Each step of the sample was followed by a period to stabilize the reactor state before the regulating control rod position was recorded. Using the regulating control rod calibration curve, the reactivity for each length of regulation control rod was recorded and given in Table 1.

Void sample position	Regulating CR position	Reactivity of void (cents)
0	207	
5	220	-2.947
10	218	-2.471
15	218	-2.471
20	208	-0.137
25	195	2.884
30	187	4.739
35	192	3.582
40	201	1.516
45	213	-1.294
50	210	-0.633
55	206	0.276
60	204	0.772
65	204	0.772

Table 1: Measurements of void coefficient of reactivity

3. Calculations: Void Coefficient of the Reactivity

To calculate the void effect on reactor the core, a detailed three dimensional computational model of the TRIGA Mark II reactor was developed using the Monte Carlo neutronics behaviour simulating code MCNP5 [5]. Because of lack of Samarium cross sections in ENDF-VI, the computer program employs JEFF3.1 as cross section library in these computations. This model includes reactor core components, surrounding graphite reflector, four beam tubes and the thermal column as shown in Figure 3. The reactor core components are comprised of 83 burned FE(s) of three different types, three control rods, one source element (in F28 position), two pneumatic systems (in F08 and F11 positions) and a central irradiation channel CC. This MCNP model is based on standard experiments performed on TRIGA Mark II reactor of ATI. These experiments include the criticality experiment, reactivity distribution experiment and radial and axial flux distribution experiment on the burned reactor core.

The developed MCNP model, incorporating the burned fuel composition, was modified to calculate the void coefficient in the central channel. The experimental procedures, described in section 3, were applied to the MCNP model to calculate the void coefficient of reactivity in the CC. The model was modified and executed for each step length separately along the axial length of the CC. The top view of the MCNP model is given in Figure 3. The vertical (YZ) view of the model shows the modelling of the sample, holding the void in vertical channel CC in Figure 4.

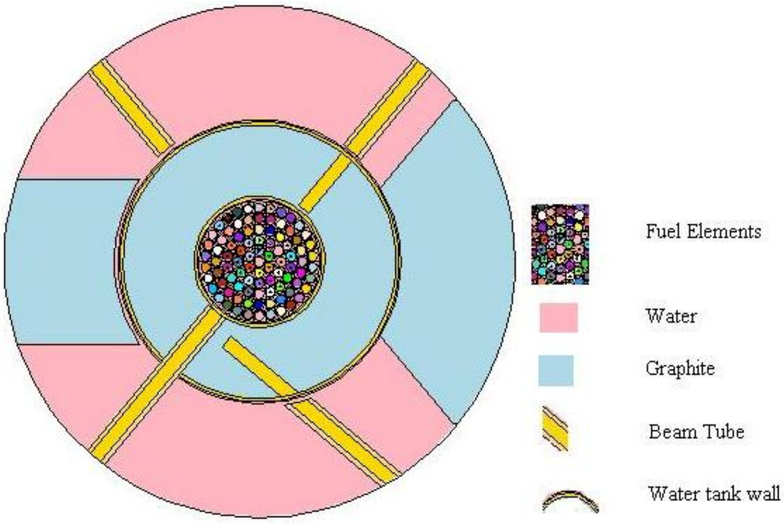

Fig 3. Top (XY) view of the MCNP model of TRIGA Mark II reactor

These calculations were carried out with total number of 200 cycles of iteration on a source size of 500 000 particles per cycles. To decrease the statistical error estimates, the first 50 cycles were skipped. For each execution, the void sample was moved 5cm up in axial direction. From the output, K_{eff} for each run was obtained to calculate the corresponding reactivity effect in dollars the using effective delayed neutron fraction β= 0.0073. The calculated results are compared with experimental observations in section 4.

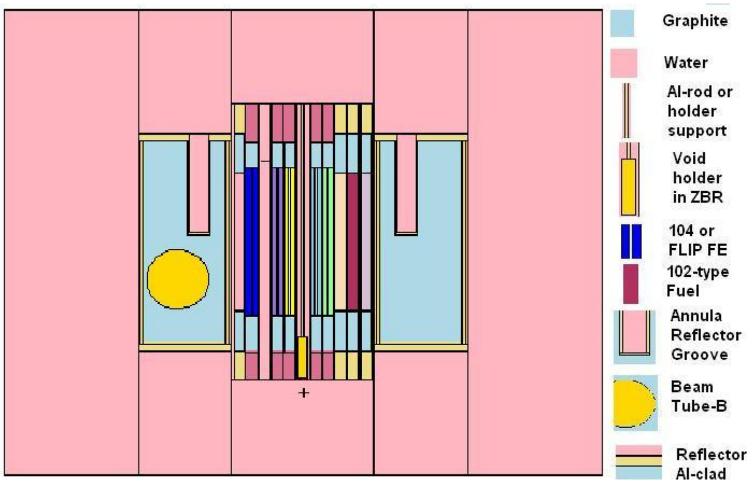

Fig 4. Vertical (YZ) view of the MCNP model of void coefficient

To eliminate the control rod effect on voids, second series of calculations were performed keeping all three CR in fully withdrawn positions. In these calculations, a source size of 5000 particles, 200 neutron cycles skipping first 50 cycles were applied to the model. These results are discussed in section 4.

4. Results and Discussions

Figure 5 shows the comparison between calculations and measurements. From these results, it is observed that reactivity effects on the TRIGA reactor due to void in the central channel is not very significant. From Table 1, it ranges from -0.044 to 0.073 cents per cubic centimetres. It is also observed that, in contrast to other water moderated reactors, void may introduce a positive reactivity in TRIGA reactors. It is due to the unique fuel properties. Figure 5 shows that MCNP predictions follow the experimental results. The fact is that a cylindrical void of about 66.47 cm^3 in CC, introduces a negative reactivity when placed at the top and bottom part of the reactor core and it add a positive reactivity when moved through the active length of the core. This may be due to the fact that the much lower neutron scattering cross section of the air provides an easy escape route to neutrons out of the core at both ends of the core. On one side, in the active part of the core, this void replaces the moderator and reduces the moderation resulting into the introduction of negative reactivity in the core. While on the other side, due to the low absorption cross section of void than water (moderator), it reduces the neutron absorption and introduces positive reactivity. It was shown theoretically and experimentally that the overall effect of this void in the CC is positive after compensating the negative reactivity due to decrease in moderation.

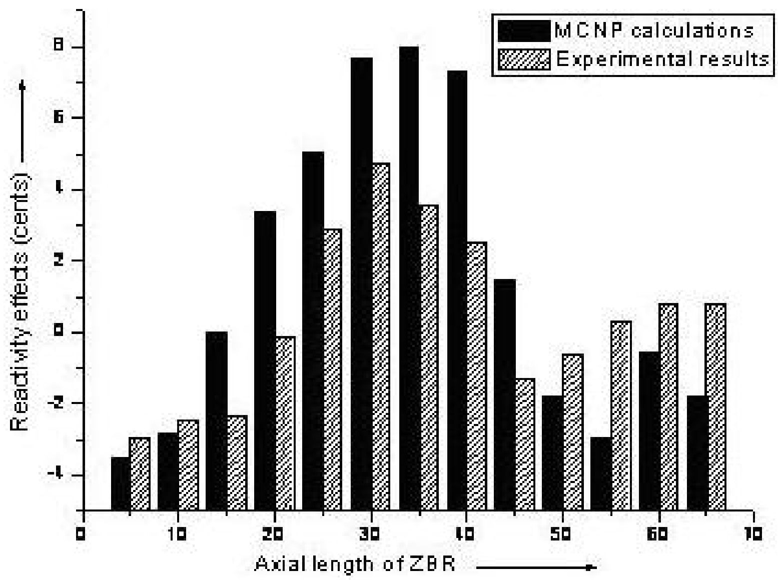

Fig 5: Theoretical and experimental comparison of void coefficient of reactivity

5. Conclusion

The MCNP model was developed for the neutronics analysis of the TRIGA Mark II reactor core. The developed model was modified to calculate the void coefficient of the reactivity in the central channel of the reactor. The calculations were verified experimentally. In contrast to other water-moderated reactors, the effect of void compensates the negative reactivity introduced due to decrease in moderation and overall introduces a positive reactivity in the CC. At the top and bottom ends of the core, the void effect is negative due to neutron leakage out of the core. Generally, the MCNP predictions follow the experimental observation along the length of central irradiation channel.

6. References

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