PRELIMINARY ANALYSIS OF EFFECT OF VANADIUM SELF-POWERED NEUTRON DETECTORS ON AP1000 REACTOR CORE PHYSICAL PARAMETERS

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ABSTRACT

For the AP1000 reactor, the Vanadium Self-Powered Neutron Detectors are installed in the instrumentation thimbles of the fuel assembly. The (n, γ) reaction of Vanadium SPNDs will impact on the neutron spectrum of the location, and finally impact on the reactor core physical parameters. But, this effect is not considered for the AP1000 reactor Nuclear Design. So, it is necessary to analyze the effect of the presence of Vanadium SPNDs on the AP1000 reactor core physical parameters. CASMO5 is used to calculate physical parameters of four typical assemblies of AP1000 reactor, and SIMULATE5 is used to calculate physical parameters of the initial cycle. The results show that the maximum absolute deviations of K-infinite, pin power, thermal flux for the assemblies are 181pcm, 6.3% and 20.1%, separately. The maximum absolute deviations of critical boron concentration, heat flux hot channel factor, nuclear enthalpy rise hot channel factor, axial offset, quadrant power tilt ratio and axial power distribution of the initial cycle are 5ppm, 0.7%, 0.5%, 0.1%,0.09% and 0.19%,separately. So, the presence of Vanadium SPNDs has a significant impact on the power distribution of pin cells around the instrumentation thimble and the thermal flux in the location of instrumentation thimble, but doesn't affect core physical parameters of the initial cycle very much. As is shown, it is very important to accurately consider the effect of presence of Vanadium SPNDs when calculating the Vanadium SPNDs current response.

Key Words: AP1000; Detectors; Reactor core physical parameters

1 INTRODUCTION

For the AP1000 reactor, BEACON[1] on-line monitoring system is used for monitoring the reactor 3D power distribution and other key safety parameters. The Vanadium Self-Powered Neutron Detectors (SPNDs) are installed in the instrumentation thimbles(IT) of the fuel assembly to measure the signals for the BEACON on-line monitoring system. The (n, γ) reaction of Vanadium SPNDs will impact on the neutron spectrum of the location, and finally impact on the reactor core physical parameters. But, this effect is not considered for NEXUS/ANC9[1] software system during the AP1000 reactor Nuclear Design. So, it is necessary to analyze the effect of the presence of Vanadium SPNDs on the AP1000 reactor core physical parameters.

In this paper, the physical parameters are calculated using CASMO5[2]/SIMULATE5[3] software system and compared between assemblies and initial cycle with and without Vanadium SPNDs. CASMO5is a multi-group two dimensional transport theory code for burn-up calculation on BWR and PWR assemblies.CASMO5 handles a geometry consisting of cylindrical fuel rods of varying composition in a square pitch array with allowance for fuel rods loaded with gadolinium, erbium, Integral Fuel Burnable Absorbers (IFBA), burnable absorber rods, cluster control rods, in-core instrument channels, water gaps, and cruciform control rods in the regions separating fuel assemblies. The code output contains the few-group cross sections (macro and micro) and reaction rates for any region of the assembly. Also, an ASCII Card Image File is created by CASMO5 for linking to SIMULATE5 code.SIMULATE5 is a multi-group three dimensional analytical nodal code for steady state analysis of both PWRs and BWRs. SIMULATE5 can be used for fuel management, core follow, and reload physics calculation. Each assembly in the core is represented in great detail both axially and radially. In the axial direction, the heterogeneities due to spacers, control rods enrichment/burnable absorber zoning and staggered assembly heights are treated explicitly. In the radial direction, the fuel assembly is divided into heterogeneous radial submeshes. The pin powers/fluxes and the detector responses are computed based on the fine scale solution obtained by the axial homogenization and radial submesh models.

2 ASSEMBLY PHYSICS PARAMETERS

To analyze the effect of Vanadium SPNDs on the assembly physics characteristic, CASMO5 is used to calculate physical parameters (e.g., K_{inf}, pin power, flux of IT) of four typical assemblies of AP1000 reactor[4]. These assemblies are selected from the initial cycle to equilibrium cycle, considering the variety of enrichment, IFBA number and the presence of Wet Annular Burnable Absorbers (WABA) and control rods. The basic parameters of four typical assemblies are shown in Table I. The geometry of the IT with and without Vanadium SPND of CASMO5 is shown in Fig. 1.

Table I. Basic parameters of four typical assemblies

Assembly No.	Average enrichment	Number of IFBA	Number of WABA	Control rod insert or not
1	3.40%	0	0	**NO**
2	4.45%	124	8	**NO**
3	4.95%	128	0	**YES**
4	4.95%	128	0	**NO**

For the four typical assemblies, the infinite multiplication factor (K_{inf}), pin power and macro group flux are calculated and compared between with and without Vanadium SPND.

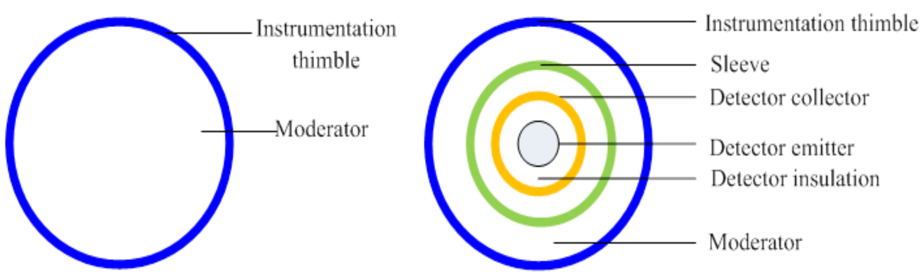

Figure 1. Geometry of the instrumentation thimble of CASMO5

2.1 K_{inf}

With CASMO5 code, the K_{inf} and the difference between assemblies with and without Vanadium SPN D at different burnup time is calculated and shown in Fig. 2.

As the result shows, the K_{inf} reduces with the presence of Vanadium SPNDs, and the maximum absolute deviation of K_{inf} is 181pcm. Also, as the burnup progressed, vanadium density decreased, which causes the absolute deviation between assemblies with and without Vanadium SPNDs decreases.

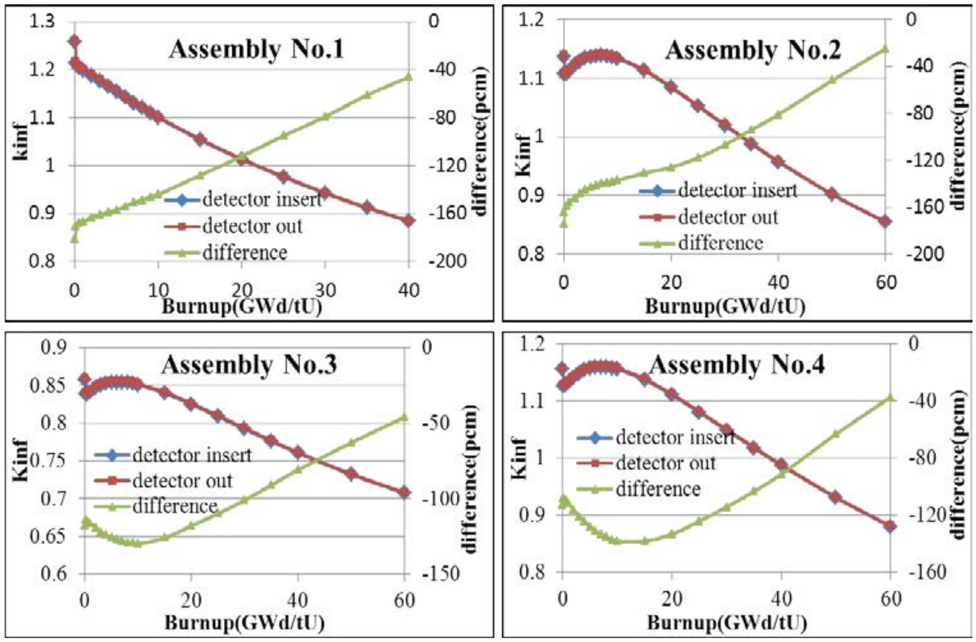

Figure 2. K_{inf} and difference of assemblies with and without Vanadium SPNDs

2.2 Pin power and flux

The pin flux and power distribution at different burnup time for the four different assemblies are

---	Det-In(IN) Det-Out(OUT) IN-OUT							
0.947 0.999 -0.052	0.994 1.025 -0.031							
0.985 0.999 -0.014	1.103 1.024 -0.011	1.018 1.024 -0.006						
---	0.995 0.998 -0.003	0.997 0.999 -0.002	---					
0.998 0.998 0.000	1.024 1.024 0.000	1.025 1.024 0.001	1.001 0.999 0.002	1.033 1.031 0.002				
1.000 0.999 0.001	1.025 1.023 0.002	1.025 1.023 0.002	0.999 0.997 0.002	1.007 1.005 0.002	---			
---	0.997 0.994 0.003	0.999 0.996 0.003	---	1.000 0.997 0.003	0.986 0.984 0.002	0.994 0.991 0.003		
0.992 0.989 0.003	1.012 1.010 0.002	1.019 1.016 0.003	0.997 0.994 0.003	1.008 1.006 0.002	0.994 0.992 0.002	0.939 0.936 0.003	0.987 0.984 0.003	
1.005 1.002 0.003	0.958 0.955 0.003	1.019 1.016 0.003	1.017 1.014 0.003	0.958 0.955 0.003	1.010 1.007 0.003	1.010 1.007 0.003	1.008 1.005 0.003	0.961 0.958 0.003

Figure 3. Pin power distribution for the assembly NO.4 at 100MWd/tU

calculated.

The maximum absolute deviation of pin power for the assemblies is 6.3%, and as the burnup progressed, it decreased. Fig. 3 shows the pin power distribution for the assembly No.4 at BOC (100MW d/tU). The comparison results shows that the presence of Vanadium SPND has a significant impact power distribution of pin cells around the IT. But, it has a little effect on the power of pin cells far away from the IT.

The presence of Vanadium SPND also has a significant impact on the macro group flux of the IT. Fig.4 shows the calculated differences of macro group flux of the IT for the assembly No.4 at different burnup time. It can be seen that presence of Vanadium SPND causes a reduction of the thermal flux as much as 20.1%.

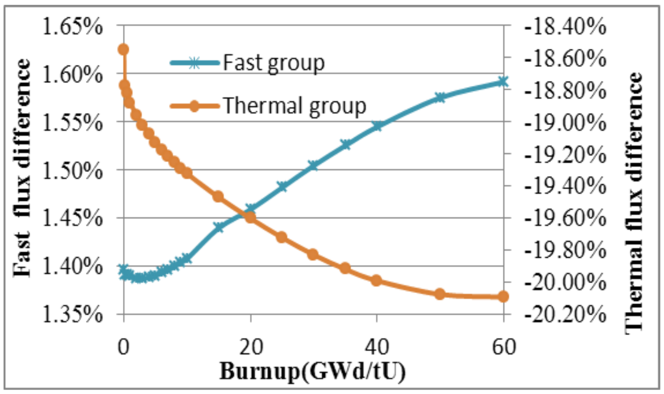

Figure 4. Differences of macro group flux of the IT for the assembly No.4

3 CORE PHYSICS PARAMETERS

For the AP1000 reactor, Vanadium SPNDs are inserted in total 42 assemblies. The radial layout of the Vanadium SPNDs in AP1000 reactor is shown in Fig. 5. The initial cycle of AP1000 is assumed to operate under the ARO mode.

As the presence of the Vanadium SPNDs mainly effect the reactivity and 3D power distribution of the core, critical boron concentration, heat flux hot channel factor (Fq), nuclear enthalpy rise hot channel factor (Fdh), Axial Offset (AO), Quadrant Power Tilt Ratio(QPTR), and axial power distribution of the initial cycle are calculated by Core physics code SIMULATE5, and compared between with and without Vanadium SPNDs.

3.1 Critical Boron Concentration

Fig.6 shows the critical boron concentration and difference between with and without the Vanadium SPNDs at different burnup time. The results show that the critical boron concentration of initial cycle with Vanadium SPNDs is less than without them, but the maximum absolute deviation of critical boron concentration of the initial cycle is only 5ppm.

3.2 Fq

The Fq and the differences between with and without the Vanadium SPNDs are calculated for the initial fuel cycle, and shown in Fig. 7. As the results show, the maximum absolute deviation of Fq of the initial cycle is 0.70%.

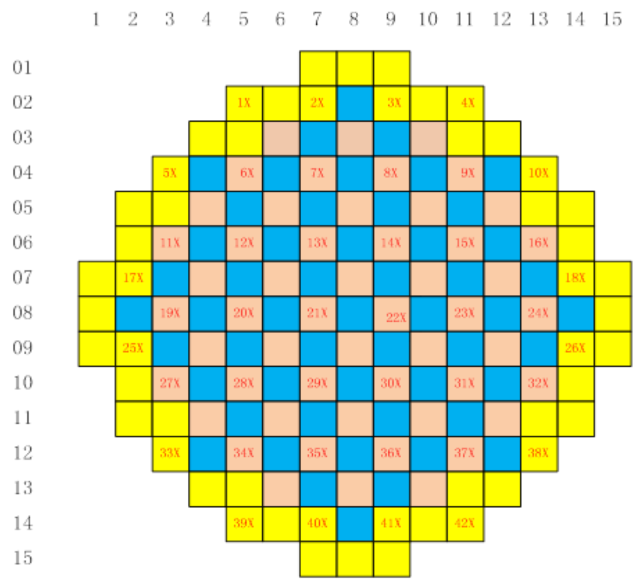

Figure 5. The radial layout of the Vanadium SPNDs in AP1000 reactor

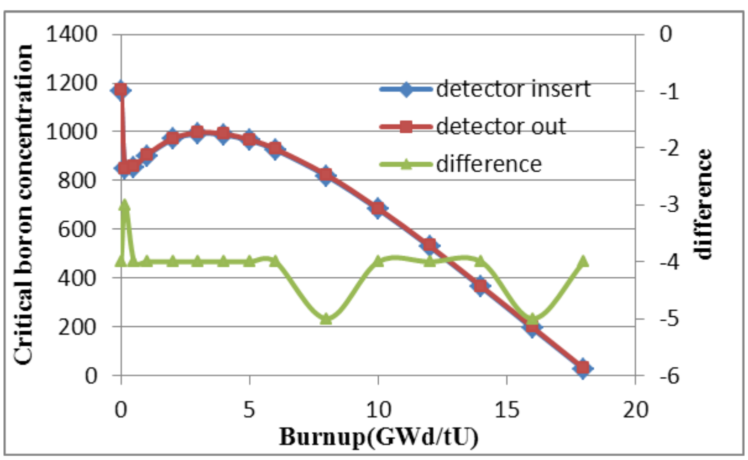

Figure 6. The critical boron concentration and difference at different burnup time

3.3 Fdh

The Fdh and the differences between with and without the Vanadium SPNDs are calculated, and shown in Fig. 8. As the results show, the Fdh with Vanadium SPNDs is more than without them, and the maximum absolute deviation of Fdh of the initial cycle is 0.50%.

3.4 AO

The AO and the differences between with and without the Vanadium SPNDs are calculated for the initial fuel cycle, and shown in Fig. 9. As is shown in Fig. 9, the maximum absolute deviation of AO of the initial cycle is -0.10%.

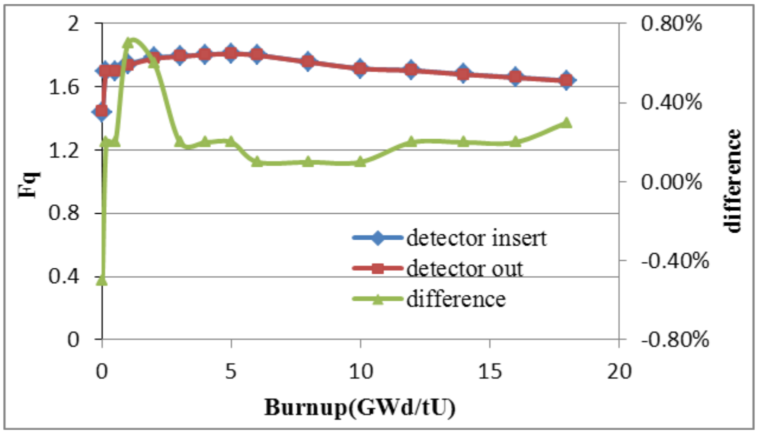

Figure 7. Fq and the difference at different burnup time

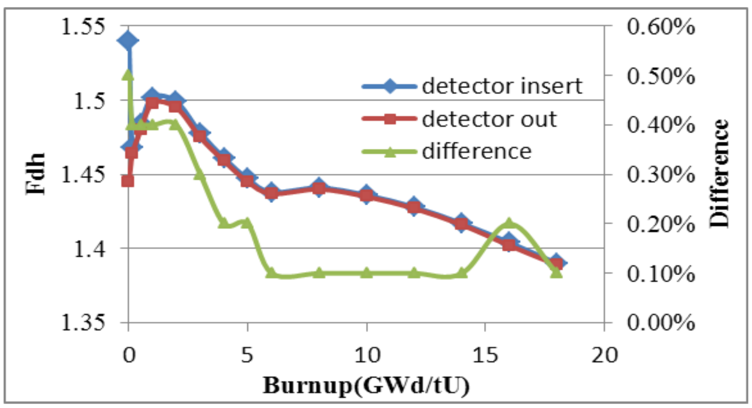

Figure 8. Fdh and the difference at different burnup time

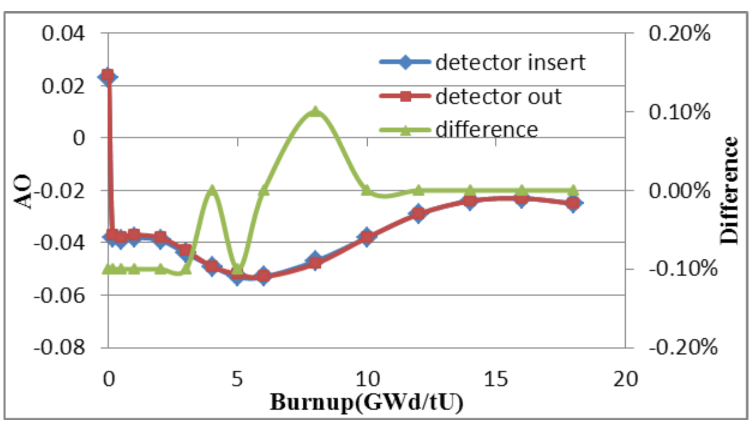

Figure 9. AO and the difference at different burnup time

3.5 QPTR

As the assemblies with Vanadium SPNDs are symmetrically arranged in the core, there is no symmetry quadrant power tilt. But, the diagonal quadrant power tilt occurs. The maximum absolute deviation of diagonal quadrant power tilt of the initial cycle is 1.0009.

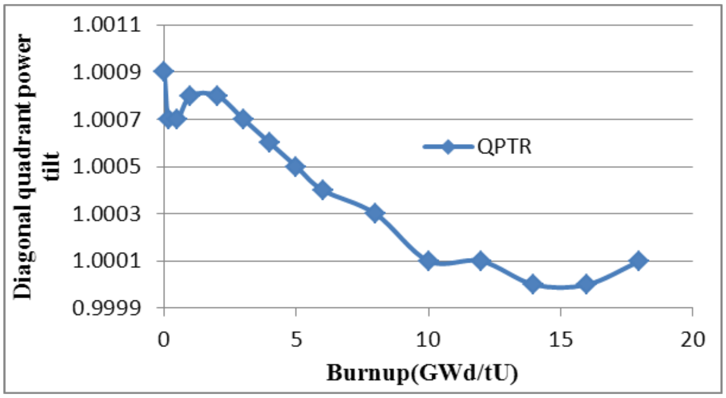

Figure 10. The diagonal quadrant power tilt at different burnup time

3.6 Axial power distribution

The axial power distribution is calculated for the initial fuel cycle, and the deviation between with and without the Vanadium SPNDs is analyzed. The axial power distribution and the deviation in the BOC(100MWd/tU)/MOC(10000MWd/tU)/EOC (18000MWd/tU)are shown in Fig. 11, 12, 13, separately. The maximum absolute deviation of axial power distribution of the initial cycle is 0.19%.

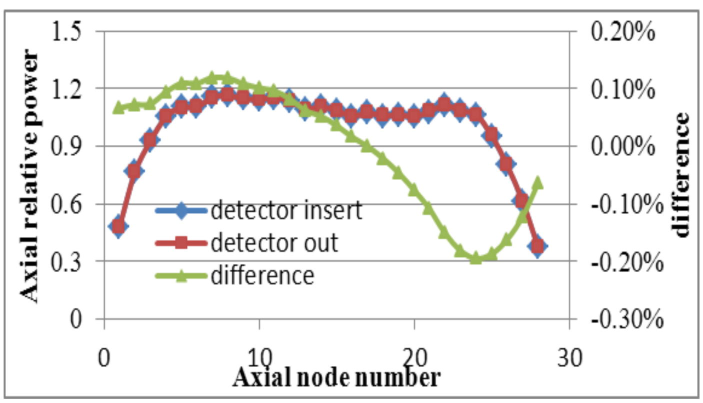

Figure 11. Axial power distribution of BOC

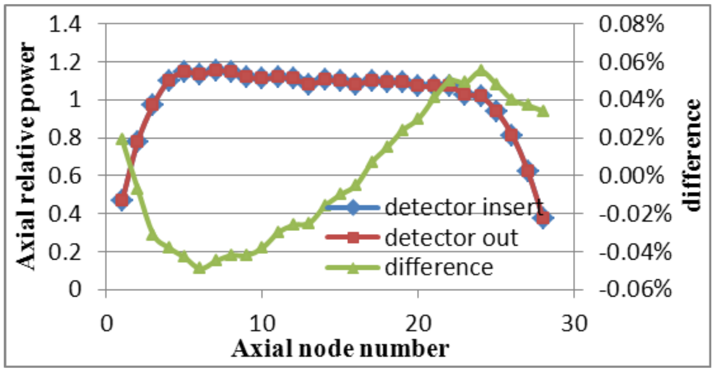

Figure 12. Axial power distribution of MOC

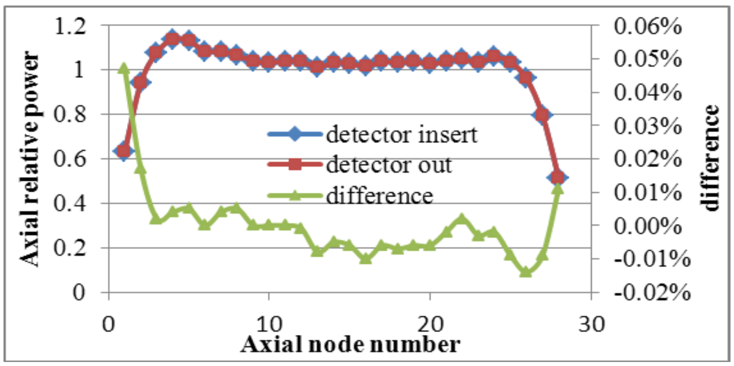

Figure 13. Axial power distribution of EOC

4 CONCLUSIONS

In this paper, in order to analyze the effect of Vanadium SPNDs on AP1000 reactor physical parameters, K_{inf}, pin power, thermal flux of four typical assemblies and critical boron concentration, Fq, Fdh, AO, QPTR, and axial power distribution of the initial cycle under ARO mode are calculated by CASMO5/SIMULATE5， and compared between with and without Vanadium SPNDs.

The results of assembly physical parameters show that the presence of Vanadium SPNDs has a little impact on the assembly Kinf, but has a significant impact on the power distribution of pin cells around the IT and the thermal flux in the location of IT, and the maximum absolute deviations of $K_{inf,}$ pin power, thermal flux for the assemblies are 181pcm, 6.3% and 20.1%, separately. For the reactor core, the presence of Vanadium SPNDs doesn't affect the core physical parameters very much, and the maximum absolute deviations of critical boron concentration, Fq, Fdh, axial offset, quadrant power tilt and axial power distribution of the initial cycle are only 5ppm, 0.7%, 0.5%, 0.1%,0.09% and 0.19%,separately.

As is shown above, the (n,γ) reaction of Vanadium SPNDs has a significant effect on the thermal flux and then changes the flux spectrum in the location of IT, so it is very important to accurately consider the effect of presence of Vanadium SPNDs and calculate the flux in the location of IT when calculating the Vanadium SPNDs current response.

5 REFERENCES

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