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XENON LOAD ANALYSIS FOR CANDU-6 WITH DUPIC FUEL

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ABSTRACT

Xenon load for a CANDU 6 reactor with DUPIC fuel has been studied. Xenon property constants were generated by WIMS-AECL code and the xenon load was calculated by RFSP code with a 3-dimensional full core model. Validation calculation has shown that the xenon load with the xenon constants from WIMS-AECL code is predicted within 2% compared to that with the xenon constants from POWDERPUFS-V code. Also, the xenon load has been calculated for various reactor power level changes and reactor shutdown conditions. The impact of the xenon load on the reactivity devices were investigated. Calculation results have shown that the xenon load of CANDU 6 loaded with the DUPIC fuel is much lower than that loaded with standard 37-element natural uranium fuel. Also, it was found that the reactivity devices can control the xenon load in the CANDU 6 reactor with the DUPIC fuel.

1. INTRODUCTION

Xe-135 is an important fission product in reactor physics because it has a very large absorption cross section and is therefore regarded as a poison material. The xenon load refers to the reactivity holdup due to Xe-135. The xenon load affects reactor power control, spatial oscillation and restart of reactor. If the DUPIC fuel is loaded in a CANDU reactor, the power distribution is different from that of natural uranium fuel core, which causes reactivity worth decrease of all the devices in the system. Especially, the function of the adjuster rod system is directly related to the xenon property when restart or reactor power change is required.

On the other hand, it is also expected that the xenon load of DUPIC fuel in CANDU reactor core will be smaller than that of natural uranium fuel core, because of effective thermal flux is lower due to higher fissile content. Therefore it is necessary to assess the xenon load accurately for DUPIC fuel CANDU core in order to confirm the function of reactivity device used to control the xenon reactivity.

In this paper, the xenon load for CANDU[1] reactor with DUPIC[2] fuel has been calculated. First, the validation calculation of WIMS-AECL[3] code for xenon property constants generation was performed, because the WIMS-AECL code is used for the cross-section generation of DUPIC fuel. For this purpose, the xenon property constants for 37-element natural uranium fuel were calculated by WIMS-AECL code and the results were compared to those by CANDU 6 design code, POWDERPUFS-V(PPV)[4]. After confirming the validity of the WIMS-AECL code, xenon loads were calculated for the case of various reactor power level change and reactor shutdown from various power level by RFSP[5]code. Also, the impact of the xenon load on the reactivity device controllability were investigated.

2. XENON PHYSICS

The xenon and iodine concentrations are space- and time-dependent. The time-dependent behaviour is described by (assuming Te-135 decays instantaneously to I-135)

$$\frac{dI}{dt} = \gamma_i \hat{\Sigma}_f \hat{\phi}_F - \lambda_i I \quad (1)$$

$$\frac{dX}{dt} = \gamma_i \hat{\Sigma}_f \hat{\phi}_F + \gamma_i I - \lambda_x X - \hat{\sigma}_x X \hat{\phi}_F \quad (2)$$

where

X = average concentration of Xe-135 ,

I = average concentration of I-135,

γ_x = direct yield of Xe-135 per fission,

γ_i = direct yield of I-135 in fission, including yields of Te-135 and Sb-135 (average over all fissions),

λ_i = decay constant of I-135,

λ_x = decay constant of Xe-135,

$\hat{\phi}_F$ = average neutron flux in the fuel,

$\hat{\Sigma}_f$ = macroscopic fission cross-section in the fuel, and

$\hat{\sigma}_x$ = microscopic Xe-135 cross-section.

Xenon Concentration

When the reactor is operating in a steady state, the concentration of iodine and xenon reach to their equilibrium values, which are

$$I_{ss} = \frac{\gamma_i \hat{\Sigma}_f \hat{\phi}_F}{\lambda_i} \tag{3}$$

and

$$X_{ss} = \frac{(\gamma_i + \gamma_x) \hat{\Sigma}_f \hat{\phi}_F}{\lambda_x + \hat{\sigma}_x \hat{\phi}_F} \tag{4}$$

The asymptotic value of the steady state xenon concentration is

$$X_{ss,\infty} = \frac{(\gamma_i + \gamma_x) \hat{\Sigma}_F}{\hat{\sigma}_x} \tag{5}$$

In RFSP, relative units(reference values) for iodine and xenon concentrations are defined as

$$i = \frac{I}{X_{ss,\infty}} \tag{6}$$

and

$$x = \frac{X}{X_{ss,\infty}} \tag{7}$$

Then, the steady-state concentrations in relative unit are given as

$$i_{ss} = \frac{I_{ss}}{X_{ss,\infty}} = \frac{\gamma_i}{\gamma_i + \gamma_x} \cdot \frac{\hat{\sigma}_x \hat{\phi}_F}{\lambda_i} \tag{8}$$

and

$$x_{ss} = \frac{X_{ss}}{X_{ss,\infty}} = \frac{\hat{\sigma}_x \hat{\phi}_F}{\lambda_x + \hat{\sigma}_x \hat{\phi}_F} \tag{9}$$

Xenon Property Constants

The thermal absorption cross section of a fuel lattice can be written in terms of absorption cross-section without Xe-135 and the increment of absorption cross-section by Xe-135.

The relative concentration is used to calculate the xenon incremental cross-section.

$$\Sigma_a(\vec{r}, x) = \Sigma_a(\vec{r}, x_{ref}) + \triangle\Sigma_a^{Xe}(x(\vec{r})) \tag{10}$$

and

$$\triangle\Sigma_a^{Xe}(x(\vec{r})) = C(\vec{r})(x(\vec{r}) - x_{ref}) \tag{11}$$

Therefore, it is necessary to calculate $\frac{\gamma_i}{\gamma_i + \gamma_x}$, xenon proportionality constant $C(\vec{r})$ and x_{ref}. From Eq. (8), the relative iodine yield is defined as :

$$\gamma_i^{eff} = \frac{\gamma_i}{\gamma_i + \gamma_x} \tag{12}$$

The equilibrium Xe-135 concentration in a flux Φ relative to that in an infinite flux is defined as :

$$x_{ref} = \frac{\Phi\ \sigma_a^{Xe}}{\Phi\ \sigma_a^{Xe} + \lambda_{Xe}} \tag{13}$$

The xenon proportionality constant is defined as :

$$C = \Sigma_f^{eff}\left(\frac{\phi_{thermal}^{fuel} V_{fuel}}{\phi_{thermal}^{cell} V_{cell}}\right)(\gamma_i + \gamma_x) \tag{14}$$

3. VALIDITY OF WIMS-AECL FOR XENON PROPERTY GENERATION

The xenon property constants generated by WIMS-AECL were compared with those generated by PPV code. It was found that the xenon properties calculated by both codes are similar.

The xenon load after reactor shutdown from 100% power level was simulated by RFSP code using xenon properties generated by WIMS-AECL and PPV. The calculations were performed for CANDU 6 with the 37-element natural uranium fuel. Fig. 1 compares the xenon behavior after shutdown. It can be seen that the xenon load variation is close each other and the maximum difference is 2%. Therefore, it is considered that the WIMS-AECL code calculates xenon properties correctly and has the validity for xenon load calculation.

4. XENON TRANSIENT ANALYSIS

The xenon reactivity transients for the CANDU 6 loaded with the DUPIC fuel were obtained from a three-dimensional diffusion calculation by RFSP code. Xenon reactivity transients after shutdown from various power levels are shown in Fig. 2, where power levels of 20%, 40%, 60%, 80% and 100% of full power were considered. Calculations were performed for two cases: the adjusters were fully in and fully out from the core. The magnitude of the peak xenon load increases with the power (flux) of the reactor before shutdown. When the adjusters are fully out, the peak xenon load is higher than the core with the adjusters fully in. If the result of shutdown from 100% full power is compared to that of the 37-element natural uranium fuel core, it can be seen that the xenon load of DUPIC core is 37% lower than that of the 37-element natural uranium fuel core.

A 30-minute xenon override capability of the adjuster rods is specified for the CANDU 6. Fig. 3 shows the xenon transient after a reactor shutdown from an equilibrium core. It can be seen that the xenon buildup of DUPIC fuel core 30 minutes after shutdown is 6.8 mk, which is 7 mk lower than that of the 37-element natural uranium fuel core. However, beacuse the reactivity worth of the adjuster rods is 10.2 mk, the adjuster rods have the 30-minute xenon override capability. Fig.4 shows startup procedure simulated by withdrawing the adjuster rods after short shutdown. The reactor power can be returned to 100% full power without excessive overpowers and exceeding the maximum channel and bundle power limits. During the power recovery, the criticality and power tilt were kept within desired values, which means that the zone controller can control the xenon induced spatial oscillation.

The reactor startup was simulated from zero power without xenon to various power levels including 20%, 40%, 60%, 80% and 100% of full power. The variation in xenon load during the first 70 hours of startup is shown in Fig.5. Note that the adjusters were fully in for these cases. The simulation has shown that the xenon loads are back to their equilibrium values after 45 hours. After 45 hours, the xenon load necessary for start up to 100% full power is 3% lower for the DUPIC fuel compared with the 37-element natural uranium fuel core.

Xenon reactivity transients after power set back from full power to 80%, 60%, 40%, 20% and 0% are shown in Fig.6. The transients were followed for about 70 hours. The adjusters were fully in for all cases. It was found that the xenon load are back to their equilibrium value within 25 - 35 hours, which is 10 hours shorter than that of the 37-element natural uranium fuel core. The xenon loads after stepback to 0% full power is 37% lower for the DUPIC fuel core compared with the 37-element natural uranium fuel core.

5. SUMMARY AND CONCLUSION

Xenon load for a CANDU-6 reactor loaded with a DUPIC fuel has been calculated and quantitatively assessed for shutdown and various power level change conditions. The xenon constant used for the xenon load calculation was generated by the lattice code WIMS-AECL and the method was confirmed by comparing the xenon load of natural uranium CANDU core to that generated by the design code POWDERPUFS-V.

The xenon load calculation on a DUPIC fuel CANDU core has shown that the maximum xenon load for shutdown from 100% power is 37% lower than that of a 37-element natural uranium fuel core. However, the adjuster rods have enough reactivity to compensate the xenon load 30 minutes after shutdown. Regarding to the startup core, the xenon load characteristics are similar for both the DUPIC and natural uranium fuel cores.

From above results, it is clear that the xenon load of the DUPIC core is lower than that of the 37-element natural uranium fuel core and that adjuster rods and zone controllers can maneuver the xenon load.

ACKNOWLEDGEMENT

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REFERENCES

1. B.G. Kim et al., "Design Manual : CANDU 6 Generating Station Physics Design Manual, Wolsong NPP 2 3 4", 86-03310-DM-000 Rev. 1, KAERI/AECL, 1995.
2. J.S. Lee et al., "Research and Development Program of KAERI for DUPIC (Direct Use of Spent PWR Fuel in CANDU Reactors)", Proc. of Int. Conf. and Tech. Exh. on Future Nuclear System, GLOBAL'93, Seattle, USA, 1993.
3. J.V. Donnelly, "WIMS-CRNL, A User's Manual for the Chalk River Version of WIMS", AECL-8955, 1986.
4. E.S.Y. Tin and P.C. Loken, "POWDERPUFS-V Physics manual", AECL Internal Report, TDAI-31, AECL 1979.
5. D.A. Jenkins and B. Rouben, "Reactor Fuelling Simulation Program - RFSP: User's Manual for Microcomputer Version", TTR-321, AECL 1991.

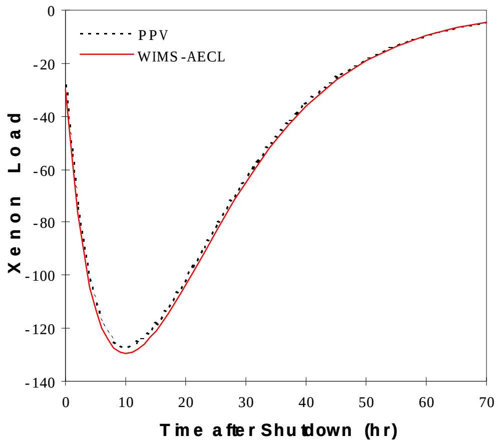

Fig. 1 Xenon Load After Reactor Shutdown From 100% Power (37-Element NU Fuel Core)

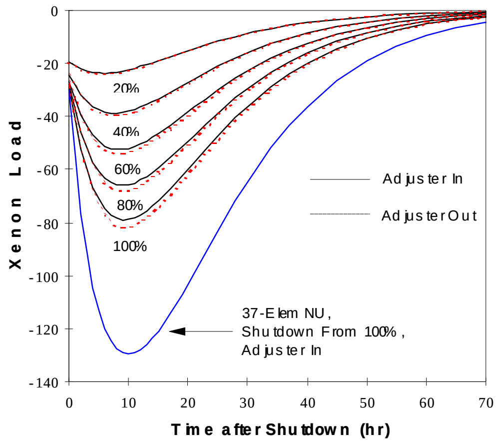

Fig 2 Xenon Load After Shutdown From Various Power Level

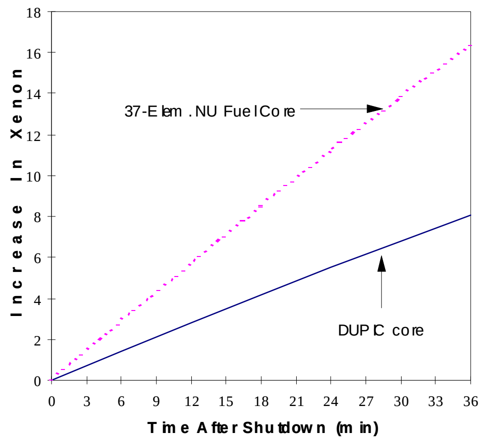

Fig.3 Xenon Transient 30 Minutes After Shutdown

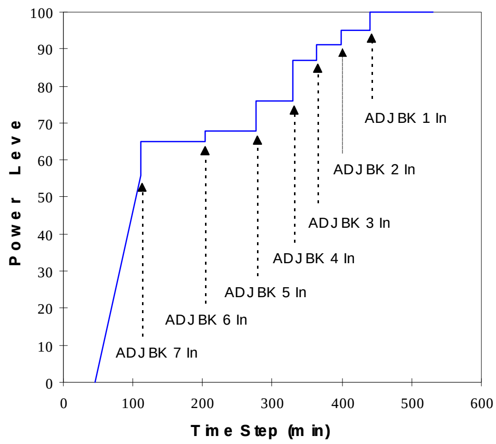

Fig.4 Reactor Power Level vs. Time in Restart from Short Shutdown

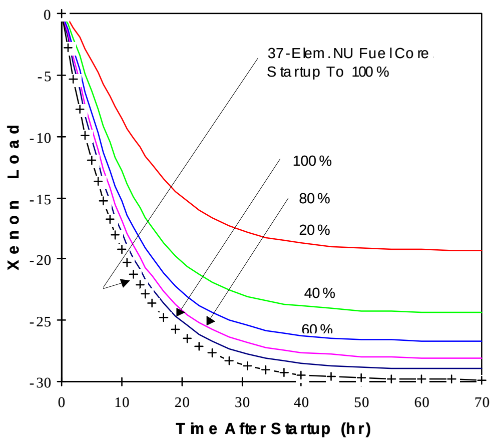

Fig. 5 Xenon Transients After Startup From Long Shutdown To Various Local Power Levels

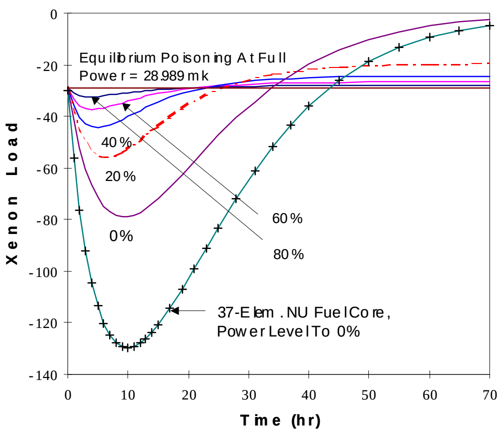

Fig. 6 Variation Of Xenon Load Following Step Power Reductions From Full Power