3.4 INTRODUCTION OF IN-CORE FUEL MANAGEMENT FOR TNPS

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ABSTRACT

Tianwan Nuclear Power Station (TNPS) owns two VVER-1000 reactors imported from Russia at present. The two reactors are put into commercial operation in 2007 and operating in the 4th fuel cycle in 2010. This report briefly describes the characteristics of fuel assemblies and in-core loadings for TNPS' VVER-1000 reactors under annual refueling scheme. As well as the plan of 18-month fuel cycle, which will be introduced to TNPS' VVER-1000 reactors in the future, is presented in the report.

1. INTRODUCTION

Two Russian AES-91 type VVER-1000 nuclear power units, with each unit capacity of 1,060 MWe, are constructed in Phase I project of TNPS located in Tianwan, Lianyun District, Lianyungang City, Jiangsu Province of China. The two units have a designed service life of 40 years and annual average load factor no less than 80%, and are expected to generate electricity of 14 billion kWh annually. AES-91 VVER-1000 nuclear power unit is an improved Russian concept based on the experience in design, construction and operation of 20 VVER type units of 1,000 MWe scale. To enhance the safety of the unit, a series of important measures have been adopted, including 4 trains for safety systems, core catcher, full-digital I&C system and double-wall containment for reactor building. The safety engineering is superior to most of the operational PWR nuclear power plants in the world and has reached the level for the 3rd generation NPP in some aspects. TNPS Phase I project was commenced for construction on Oct.20, 1999. Units 1&2 were put into commercial operation on May 17 and Aug. 16, 2007 respectively. Units 1&2 have been in safe and reliable power operation continuously for three fuel cycles respectively.

According to Fuel Supply Contract signed with Russia, the two units are supplied fuel assemblies for initial core and the first three refuel by Russian Joint Stock Company "TVEL". And the fuel management scheme is elaborated by the Russian Research Center "Kurchatov Institute" with proposal of Chinese design institutes. This report describes reactor core of TNPS VVER-1000, introduces the main features of in-core fuel management under annual refueling scheme, background and implementation plan of long cycle fuel management.

2. REACTOR CORE DESCRIPTION

2.1 Reactor core

The reactor core is hexagon and consists of 163 hexagonal fuel assemblies. Core fuel height is 354 cm (hot state), and core equivalent diameter is 3.16 m. Core radial reflector is composed of ferroalloy barrier and coolant flow channels.

2.2 Fuel assembly

Advanced fuel assembly (AFA) loaded in TNPS VVER-1000 core incorporates 311 fuel rods, 18 control rod guide tubes, 1 central tube and 1 instrumentation tube, a total of 331 elements. There are three FA structures are used in fuel cycles. Fuel bundle of FA structure 1 consists of uranium fuel rods only containing fuel of single enrichment. In the central part of FA structures 2 and 3 there are located fuel rods with increased enrichment as compared with fuel rods in the peripheral zone. Such design allows depressing non-uniformity of power distribution over FA. Additionally, fuel bundle of FA structure 3 contains seven fuel rods with gadolinium (UO_2 - Gd_2O_3 fuel elements), and enrichment of fuel elements with gadolinium accounts to 3.3% and Gd_2O_3 content in the fuel is equal to 5% by mass. Structures of FA are showed in figure 1.

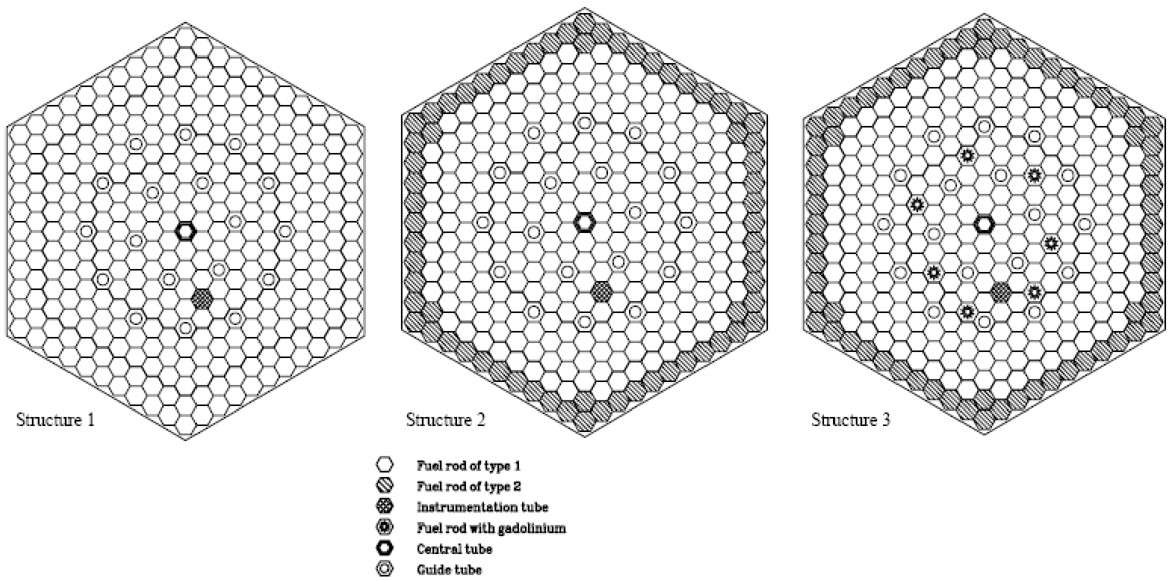

Figure 1 Structure of FA

Table 1 contains description of all FA types loaded in TNPS VVER-1000 core. In initial core there are FAs of types 24B20, 24B36 and 36B36 containing removable burnable absorber rods (BAR) that are located in guide tubes of CPS CR. Boron with natural content of isotopes is used as a burnable absorber. Mass boron concentrations in the BAR are equal to 0.020 g/cm^3 (FAs of type 24B20) and 0.036 g/cm^3 (FAs of type 24B36 and 36B36). During the first refuel BARs are removed from the mentioned FA types.

Table 1 Description of FA types

FA type	^{235}U average enrichment，%	Number of fuel rods / ^{235}U enrichment，%		Characteristics of fuel rods with gadolinium		
		Type 1	Type 2	Number of fuel rods with Gd_2O_3	^{235}U enrichment of fuel rods with Gd_2O_3，%	Gd_2O_3 weight content，%
36G7	3.61	238 / 3.7	66/3.3	7	3.3	5
40G7	4.00	238 / 4.1	66/3.7	7	3.3	5
41	4.10	311 / 4.1	-	-	-	-
24 24B20 24B36	2.40	311 / 2.4	-	-	-	-
36 36B36	3.62	245 / 3.7	66/3.3	-	-	-
16	1.60	311 / 1.6	-	-	-	-

2.3 Arrangement of CPS CR

TNPS VVER-1000 core can arrange up to maxmium121 CPS CRs according to the number of CPS CR drives, that to say control rod can be located in all FAs except 42 FAs in the core peripheral zone. Such design allows to flexibly layout the CPS CR to adapt for different core loading and increase the shutdown subcriticality. In initial core 42 BARs are used, and 36 of them are located in the central part of the core, so only 85 CPS CRs are arranged. In the following fuel loading the number of CPS CRs is extended up to 103 although in principle there are no limitations for making available the maximum 121.

All CPS CRs are distributed over 10 groups according to function, each of includes 6~12 CRs. The groups 1 to 7 are used to emergency protection; the groups 8 to 10 are used to adjustment and control, a total of 22 CRs, in which the group 10 is main adjustment group including 6 CRs. In addition, a CPS CR group is used for immediately depressing reactor power namely APP group which is selected based on the neutron physical calculation results. For initial core, APP group is selected to locate in central 6 CRs of 2^{nd} group, but for the following 2^{nd} to 4^{th} loadings, APP group is selected to locate in central 6 CRs of 6^{th} group. The arrangement of CPS CR group from the first refuel is showed in Figure 2 (the figure shows the serial number of FAs and CPS CR groups).

Absorber element includes two absorbing materials, i.e. B_4C and Dy_2O_3*TiO_2. The lower part of absorber rod contains Dy_2O_3* TiO_2 which is able to improve chemical stability, decrease neutron absorption, and permit to extend CRs life (from the 3-year life of pure B_4C absorber extend to 10 years life of combined absorber). CPS CR parameters are showed in Table 2.

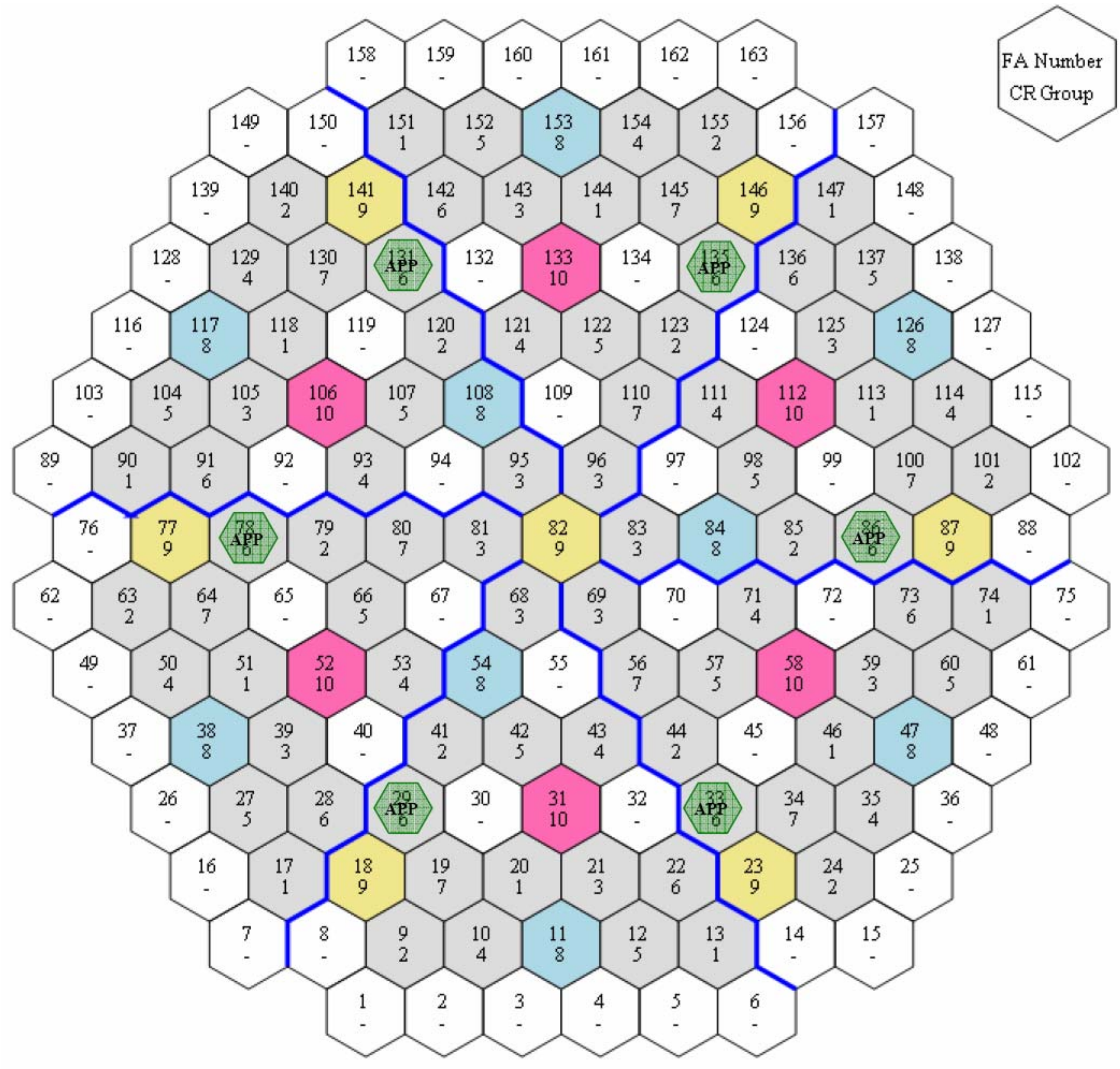

Figure 2 Arrangement of CPS CR group from the first refuel

Table 2 Parameter of CPS CR

Parameter, unit	value
Number of absorber elements per CPS CR, pcs	18
Absorber material:	
upper part / lower part	B_4C / Dy_2O_3*TiO_2
Column height of absorbing material, m	
total/upper part / lower part	3.5 / 3.2 / 0.3
Density of absorbing material（not less than）, g/cm^3	
Upper part (B_4C) / lower part (Dy_2O_3*TiO_2)	1.7 / 4.9
Outside diameter of absorber element cladding, mm	8.2
Thickness of absorber element cladding, mm	0.5
Material of absorber element cladding	Alloy 42XHM

2.3 Arrangement of neutron and temperature measurement channel

Neutron and temperature measurement channels (NTMCs) are located in 54 FAs during TNPS Units 1 and 2 operating. NTMCs are able to real time measure coolant temperature at inlet and outlet of core by platinum thermocouple as well as in-core power field by rhodium self-powered neutron detector. 54 NTMCs are distributed over 4 groups, each group includes 13 or 14 NTMCs. Arrangement of NTMC is showed in Figure 3 (the figure shows the serial number of FAs and NTMC groups).

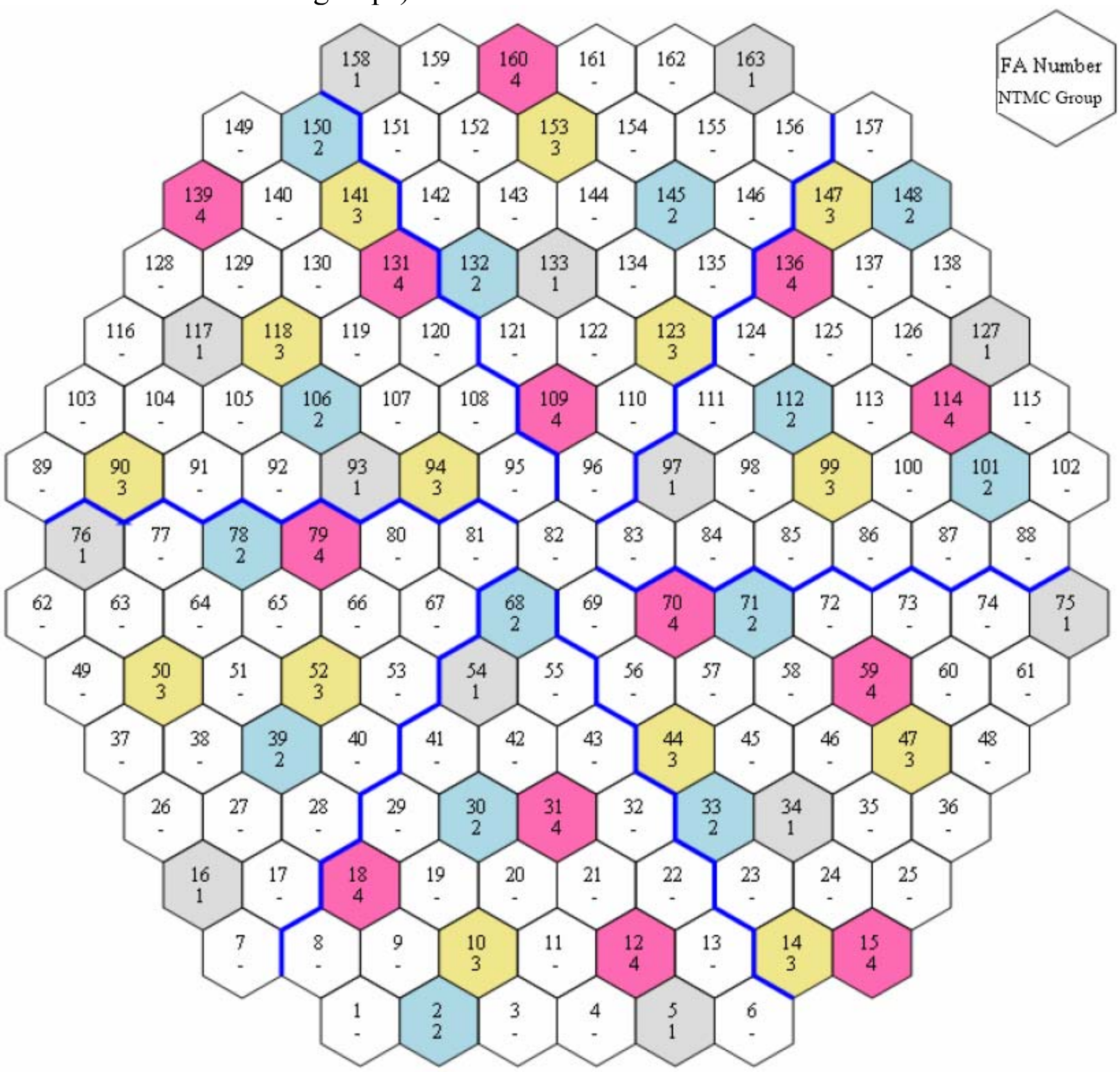

Figure 3 Arrangement of NTMC

3. FUEL LOADING PATTERN

3.1 Initial core

In initial core, three ^{235}U enrichment FAs are loaded: 54 FAs with enrichment of 1.60%, 67 FAs with enrichment of 2.40% and 42 FAs with enrichment of 3.62%, the core average enrichment is equal to 2.45%. The traditional “high leakage” loading pattern is used in the initial cycle: the FAs with high enrichment (3.62%) are located in core periphery; FAs with low enrichment (1.60% and 2.40%) are located in core central part. Such pattern allows more effectively utilizing energy capacity of FAs withdrawn after the first and the second years operation. The initial core is 30 ° symmetric fuel loading pattern that can be see in figure 4 (the figure shows fuel cycle and fuel type).

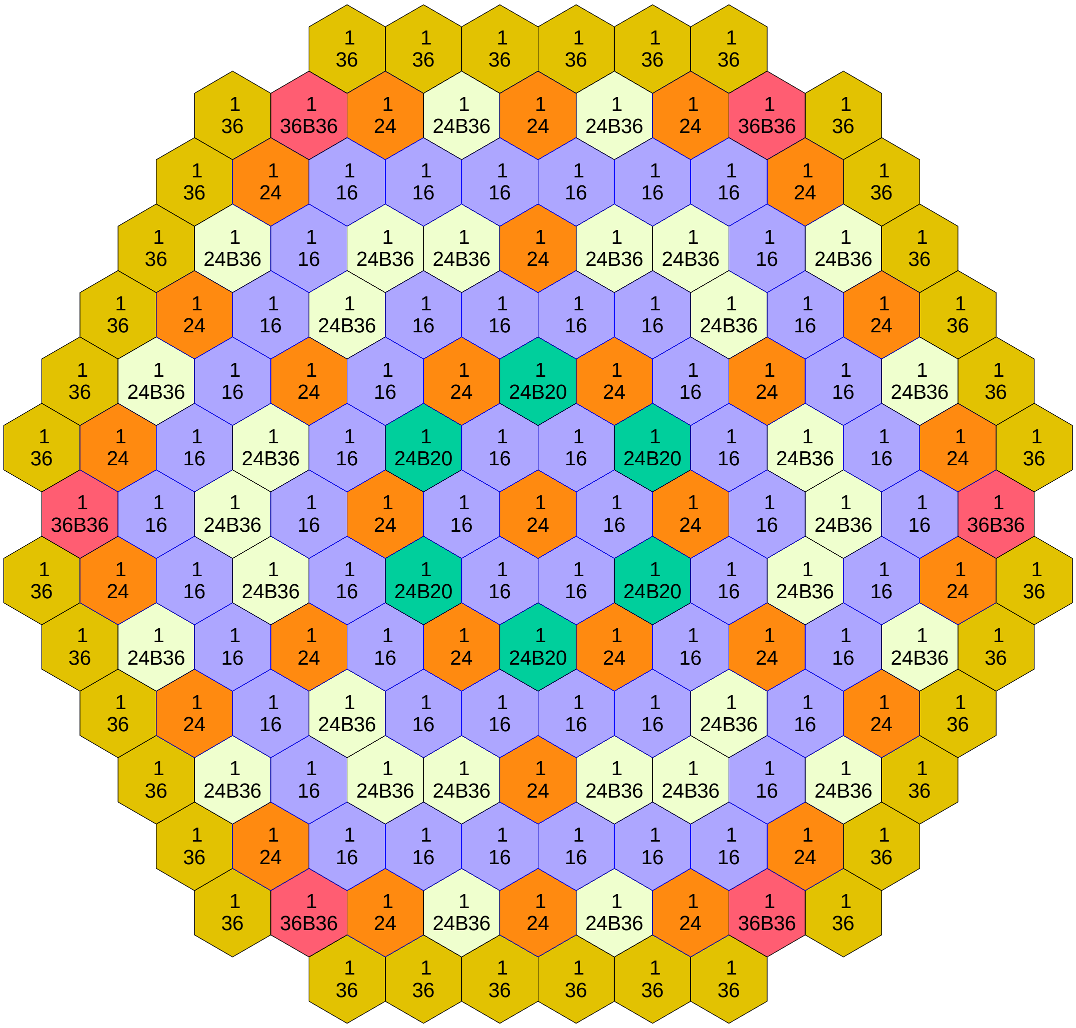

Figure 4 Pattern of the initial core fuel loading

3.2 Transition cycle core

The transition cores are loaded three fresh FA types with average fuel enrichment of 3.606% (type 36G7), 3.997% (type 40G7) and 4.1% (type 41). Starting from 2nd cycle, 18 FAs of the last year are arranged in the core periphery being closest to the reactor vessel. Such loading patterns allow reducing the fast neutron flux to the vessel and increasing the emergency protection effectiveness. Transition cycle cores are 60 ° symmetry fuel loading pattern, the 4th cycles fuel loading pattern is showed in Figure 5 (the figure shows fuel cycle and fuel type).

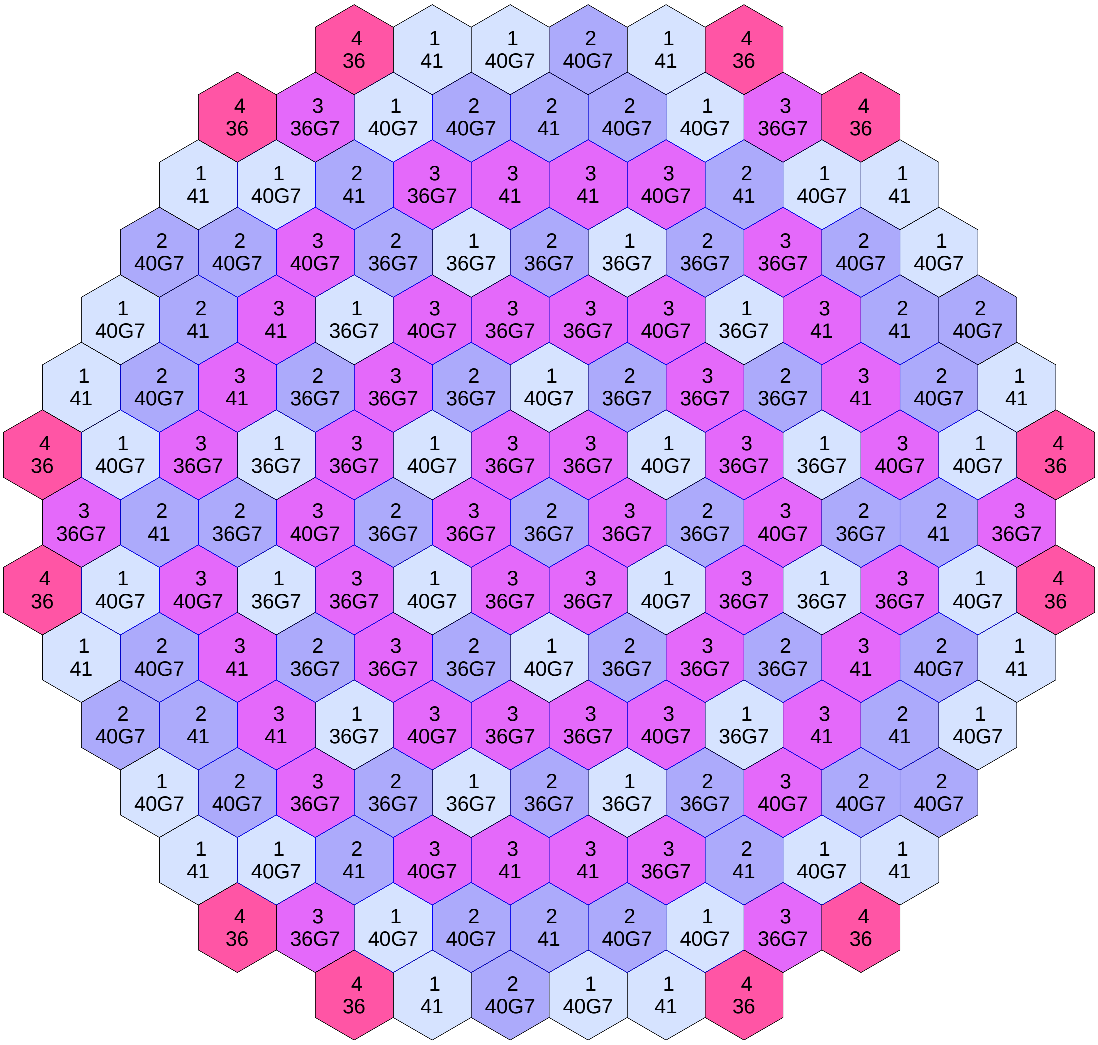

Figure 5 Pattern of the fourth cycle fuel loading

3.3 Steady-state cycle core

According to the current annual core refueling management scheme, steady characteristics of fuel burnup are reached in 6^{th} cycle. The number of refueled FAs is 48 or 49 and average ^{235}U enrichment of fresh fuel is equal to 3.925% or 3.919%. 30 or 31 FAs are loaded in the central part of the core during 3 cycles and 18 FAs are used for 4 cycles located in peripheral part of the core during 2 or 3 cycles. Such loading pattern is able to minimize the difference between average and maximum fuel burnup of unloaded FAs. Cycle length is about 300 EFPD, average unload FAs burnup is amount to about 43MWd/kgU and maximum unload FA burnup is amount to about 46MWd/kgU (limitation of FA burnup is 49MWd/kgU). 1/3.5 cycle refueling scheme achieves improved economic objectives.

Fresh FAs loaded in core are the basis of three FA types with average fuel enrichment of 3.606% (type 36G7), 3.997 %(type 40G7) and 4.1%(type 41). Because of locating the 18 FAs of last (fourth) year operation in peripheral part of the core, the “partial low leakage” core conditions are realized for decreasing fast neutron flux to the reactor vessel. In steady-state cycle, the schemes of FA arrangement are steady and repeat themselves in every third refueling of the reactor. FA arrangement in steady-state cycle is 60 ° symmetry; the 8th fuel cycle loading pattern under annual refueling scheme is showed in Figure 6 (the figure shows fuel cycle and fuel type).

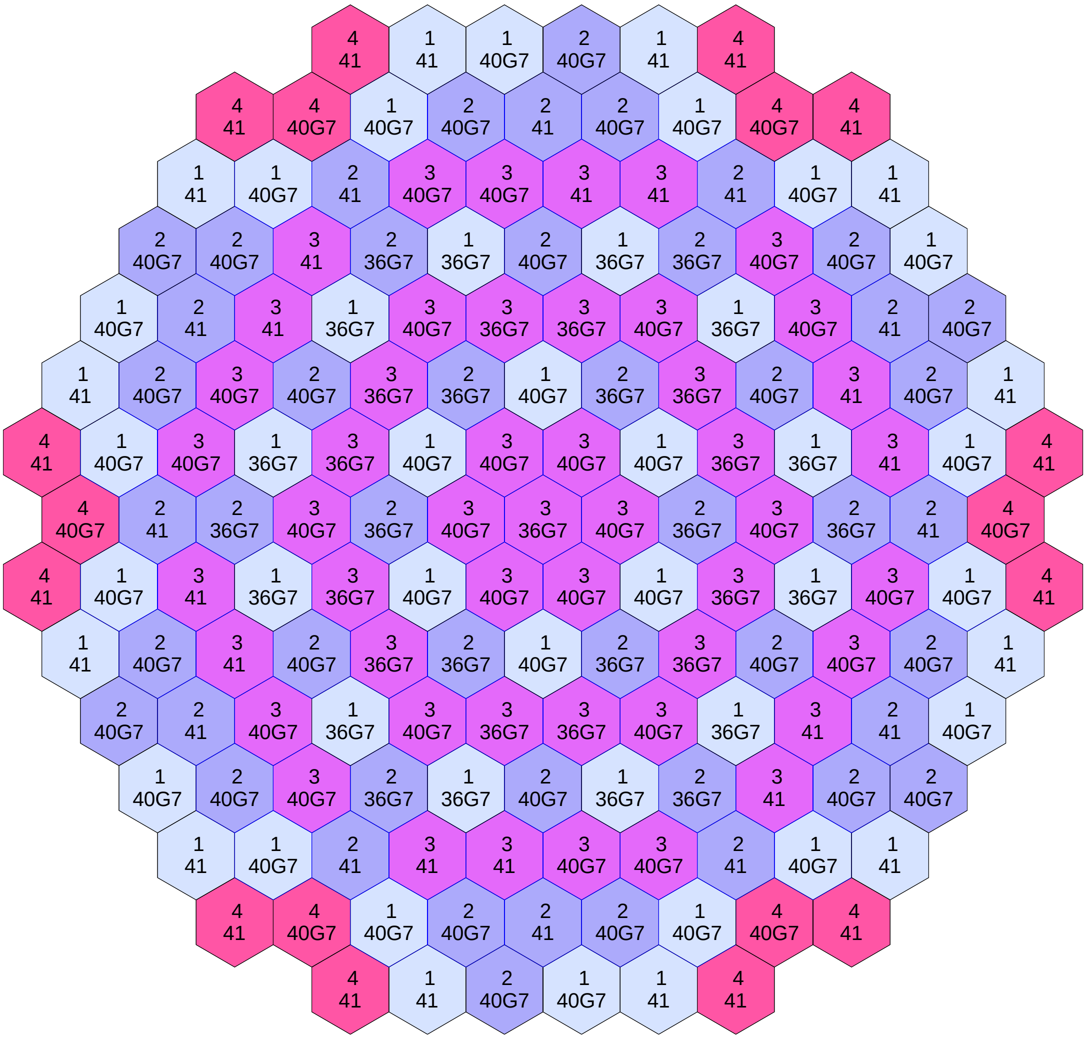

Figure 6 Pattern of the eighth fuel cycle loading

4. ABOUT LONG CYCLE FUEL MANAGEMENT

4.1 Introduction of background

In 2008, TNPS has set up a special work group to develop a serial of project program for long cycle refueling work. TNPS is plan to execute transition to 18-month fuel cycle based on successful experience in long cycle refueling project of Russian reference VVER-1000 nuclear power plant and detailed verification. The aims of long fuel cycle are to realize the flexibility cycle length for preventive maintenance requirements, improve the annual load factor and economic benefit.

4.2 About FA used for long fuel cycle

According to the experience of Russian Reference nuclear plant, a high-performance FA TVS-2M is recommended to use in long fuel cycle. Compared to AFA used in TNPS VVER-1000 core now, TVS-2M has significant design improvement, for example:

- "rigid skeleton" provided by welding spacing grid to guide tubes;
- Number of spacing grid is decreased from 15 pcs to 13 pcs but height of spacing grid is increased from 20cm to 30cm;
- height of fuel column is increased, outside diameter of fuel pellet is increased and central hole diameter of fuel pellet is decreased.

The above design improvement allows increasing FA structural stability and fuel load, extending the maximum FA life to 40,000 hours and increasing the maximum design limit of fuel burnup amount to 60MWd/kgU. Comparison of core height between TVS-2M with AFA is showed in figure 7.

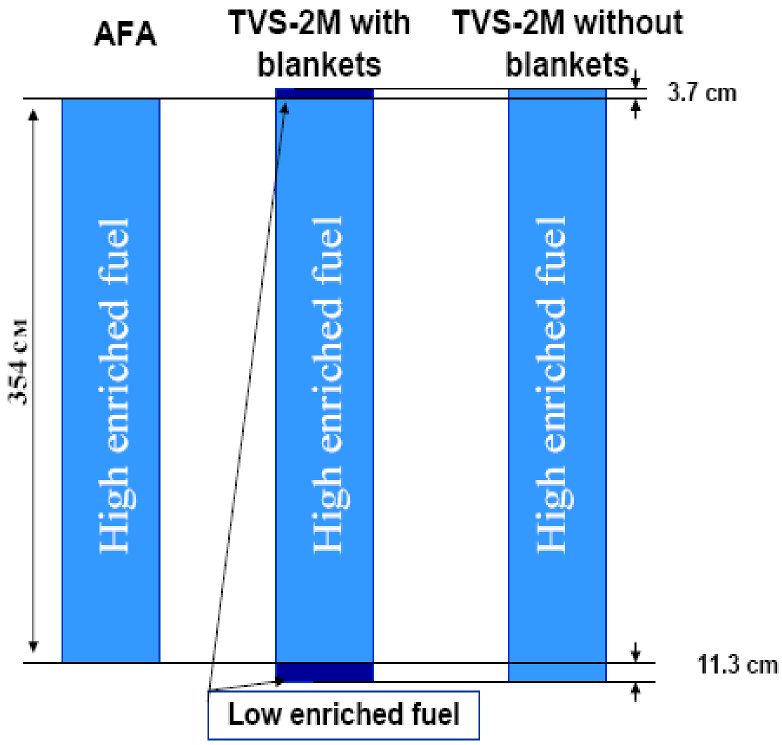

Figure 7 Comparison of core height between TVS-2M with AFA

4.3 Implementation plan for TNPS long fuel cycle

Six pilot TVS-2M (with "blanket") FAs are planed to load into Unit 1 Cycle 5 (4th refueling) in 2011 in order to verify the compatibility of mixed core. Beginning from the 8th cycle (the 7th refueling) in 2014, TNPS Units 1 and 2 are plan to gradually increase fuel cycle length during the follow-up three transition fuel cycles and finally reach to 480EFPD in 11th cycle. During the transition cycles, TNPS need perform twice preventive maintenance every year although the fuel cycle lengths are increased. After up to 480EFPD cycle length, the model of annual preventive maintenance for TNPS units becomes the following: once every year for previous two years and twice for the 3rd year, repeat themselves in every third year, i.e. " once - once – twice - once - once - twice ...". This model reduces the number and average time of annual preventive maintenance.

5. CONCLUSION

In-core fuel management for TNPS VVER-1000 has the following characteristics:

a) Core radial reflector of TNPS VVER-1000 is iron-water mixed reflector. Reactor core is loaded hexagonal FAs of three structure types. Number of CPS CR loaded in core can be up to maximum 121 and the number of NTMCs arranged in core is 54.

b) The traditional “high leakage” loading pattern is used in the initial cycle. Starting from 2^{nd} cycle, the "partial low leakage" loading patterns are applied in the core. Fresh FAs loaded in core are on the basis of three FA types i.e. 36G7, 40G7 and 41. 1/3.5 cycle refueling scheme achieves improved economics of nuclear power station.

c) TNPS plans to load 6 pilot TVS-2M FAs into Unit 1 Cycle 5 to verify the compatibility of mixed core, and implement long fuel cycle from 7^{th} refueling in 2014, ultimately reach to 480EFPD cycle length through three transition cycles.

NOMENCLATURE

TNPS: Tianwan Nuclear Power Station
I&C: Instrumentation and Control
PWR: Pressurized water reactor
NPP: Nuclear Power Plant
AFA: Advanced fuel assembly
FA: Fuel Assembly
BAR: Burnable Absorber Rod
CPS: Control and Protection System
CR: Control Rod
APP: Accelerated Preventive Protection
NTMC: Neutron and Temperature Measurement Channel
EFPD: Effective Full Power Day