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DESIGN CONCEPT OF SMALL LONG-LIFE PWR USING SQUARE AND HEXAGONAL THORIUM FUEL

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ABSTRACT

Long life reactor is a nuclear power plant which can be operated 10-30 years of operation without the need for refueling. Such Nuclear Power Plant is very good to supply electricity in remote area in Indonesia and in general outside Java Bali Area. Here, a Design study of small long-life Pressurized Water Reactor using thorium cycle has been performed with fuel fraction 60%. The neutronic calculations were performed by PIJ SRAC code using nuclear data library based on JENDL 4.0, while the core burn up calculations were optimized in whole X-Y-Z geometry by COREBN. The strategy is by the reduction of moderator by adopting tight lattice model based on hexagonal geometry cell and by the use of Pa-231 as burnable poisson material which give good long life core during burnup time. The optimization of 350 Mwt small long life PWR based on thorium nitride fuel system has excess reactivity as low as about 1% dk/k and flatted power distribution during its operation.

Keywords: small long-life, thorium fuel, conversion ratio, burn up, excess reactivity, power distribution.

INTRODUCTION

Increasing energy demand from industry and public sector is really relied on the total population in each country. Currently Indonesian government has planned to build many new power plants overcoming huge electricity demand by using all definitely energy scenarios, including nuclear. Small long life Nuclear Power Plant (NPP) with considering technological, geographical and economical aspect are a good candidate for new energy resources for remote area in Indonesia such as many islands outside Java-Bali [5, 9].

Effort to design small thermal reactor is not a simple work. The fuel system which has relatively large internal conversion ratio could guarantee thermal nuclear reactor operating long time continuously without increasing reactivity swing during burn up time. Neutronic performance of small long-life PWR has been investigated [1]. We had employed strategies such as usage of thorium fuel cycle; adopt tight lattice and additional protactinium in the fuel. Here long life PWR study is performed by using thorium nitride which tight lattice concept applied in square and hexagonal cell geometry.

DESIGN CONCEPT

A study of long-life core with the reduction of excess reactivity during 10 years operation without refueling.is focused on optimization of thorium cycle, tight lattice and additional of protactinium in the fuel. Thorium that has relatively large internal conversion ratio and high capacity factor is suitable to fulfill advance fuel for future NPP because it has good characteristic for long time operation. New fissile material of U-233 can be produced during burn up time by conversion for each fertile material of thorium. Thorium nitride has chosen because mixed nitride has not only high fuel density and good thermal conductivity but also good neutronic performance. The excess reactivity of mixed nitride during burn up time is better than mixed oxide and carbide [1].

In order to obtain small core with low reactivity swing, tight lattice concept is adopted by increasing fuel volume fraction and employing optimum fissile percentage strategy. We characterized burn up level of each square lattice and hexagonal lattice geometry with larger fuel-moderator ratio. However, the usage of high percentage U-233 material has consequences large reactivity during burn up, especially in Beginning of Life (BOL). Burnable poisson is introduced to reduce initial reactivity in BOL. Protactium which has a large capture cross section could be acted as burnable poisson.

CALCULATION METHOD

The SRAC system based on latest nuclear data library JENDL.4.0 has performed to conduct the cell burn up calculation. The collision probability method code which is developed by the Japan Atomic Energy Agency (JAEA) covers cell calculation for the square and hexagonal cell geometry as shown in Figure-1. The calculation results macroscopic group cross section in energy range from 10-5eV to 10 MeV. Finally, core burn up calculation is optimized by utilizing both cross section and history files in the COREBN code. Optimization of pressurized water reactor has been done as long as 10 years or more with a thermal power level of 350MWt. The three-dimensional geometry (X-Y-Z) PWR core is

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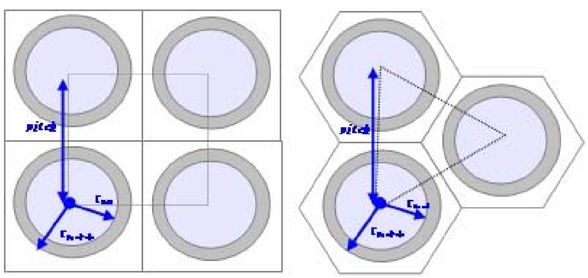
designed to operate in critical condition 10 years without refueling or fuel shuffling using thorium- fuel system with optimal U-233 -Protactinium percentage and advanced alloy material (ZIRLO) as cladding

RESULT AND DISCUSSIONS

A study of long-life core with the reduction of Design of Small long life PWR with thermal power 350 MWt are considered in fissle percentage between 3% and 8% U-233. Some parameter have been investigated in cell burn up calculation by following parametric survey as shown in Table-1.



(a) Square (b) hexagonal

Figure-1. (a)Square and (b)hexagonal cell geometry.

Table-1. Survey of parameter.

Parameter	Specification
Thernal Power	350 MWt
Refueling Period	10 years
Fuel	Th-Nitride
Cladding	ZIRLO
Coolant/Moderator	Light Water (H_20)
U-233 Percentage	3.0%-8.0%
Burnable Poisson	up to 7.0% Pa-231
Fuel Density	11.6 g/cm^3
Smear Density	90% T.D
Water Density	0.64 g/cm^3
Pin Cell Geometry	Square and hexagonal
Fuel Fraction	40-60%
Pin Pitch	1.4 cm

The thorium and uranium fuel performance with vary fuel fraction are resulted in the begining of life as shown in Figure-2. The multiplication factor in the begining of life of thorium fuel with 4.8% uranium 233 is slightly better than uranium fuel with enrichment of 4.8% . Thermal cycle in the thermal environment is superior than uranium cycle in the therm of producing core with high internal conversion ratio. Fuel fraction 60% give good result in both thorium fuel and uranium fuel with low excess reactivity.

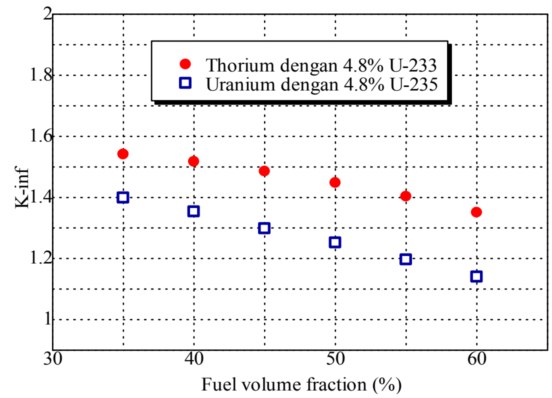


Figure-2. k-inf vs fuel fraction in the begining of life for thorium and Uranium fueled.

Thorium nitride fuel which has good thermal conductivity and high density had give the best result for reducing excess reactivity during burn up time thorium with mixed nitride is better than mixed oxide and carbide for reduction of excess reactivity during burnup time[1]. However, addition of protactinium which has large capture cross section is the most strategy effort to reduce initial reactivity in the beginning of life. The effect of Protactinium to the infinite multiplication factor during burn up for 3% U-233 percentage of thorium nitride fuel is shown in Figure-3. The Thorium nitride fuel with higher addional protactinium results in lower k-inf pattern change during burn up operation.

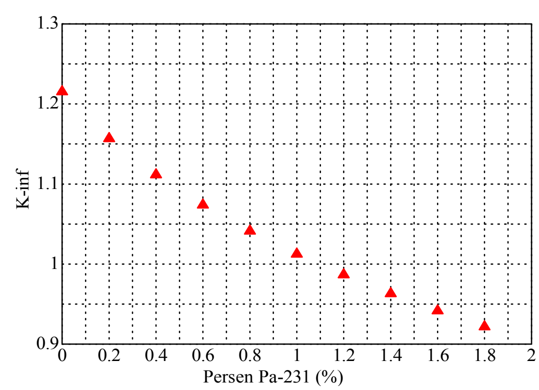


Figure-3. The effect of Pa-231 to the k-inf during burn up for 3% U-233 percentage- thorium nitride fuel.

Optimization of 350 MWt long life PWR during 10 years of burn up without refueling based on 6% U-233 percentage with 4.4% Pa-231, 7% U-233 percentage with 5.6% Pa-231, 7% U-233 percentage with 5.7% Pa-231,

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8% U-233 percentage with 6.8% Pa-231 and 8% U-233 percentage with 7% Pa-231 for square cell geometry are performed by COREBN. The result shows that the usage of all kind fuel give k-inf pattern almost same as shown in Figure-3, However, the usage of 6% U-233 and 4.4 % Pa-231 give excess reactivity about than 2% dk/k in post BOL.

However, k-inf pattern during burnup of 350 MWt long life PWR without refueling for hexagonal cell geometry is slightly different. The usage of U-233 as fissile and Pa-231, as BP, give more significantly result for hexagonal cell geometry case than square . Because of reduction of moderator volume, moderated neutron new fission and absorps by BP after realesed.

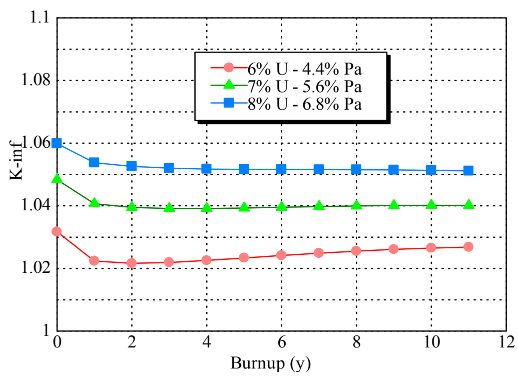

Figure-4. k-eff change during burn up for 350MWt long life PWR without refueling for square cell geometry.

CONCLUSIONS

A design of small long-life Pressurized Water Reactor using thorium cycle has been performed with fuel fraction 60%. the strategy of reduction moderator until tight lattice using hexagonal geometry cell give good long life core during burnup time by helping Pa as burnable poisson material. The optimization of 350 Mwt small long life PWR based on thorium nitride fuel system has excess reactivity as low as 1% dk/k.

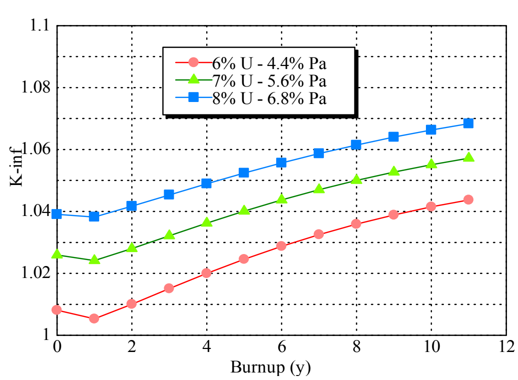

Figure-5. k-eff change during burn up for 350MWt long life PWR without refueling for square cell geometry.

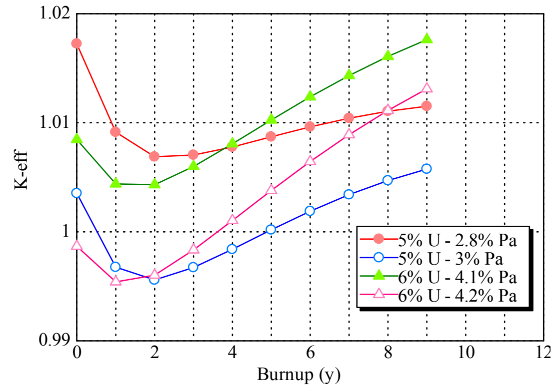

Figure-6. Optimization result of 350MWt long life PWR without refueling using square cell geometry.

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