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Submission date: 08-Jun-2023 02:17PM (UTC+0700)
Submission ID: 2111602680
File name: B1._Ariani_2020_J._Phys.__Conf._Ser._1568_012015.pdf (747.68K)
Word count: 2241
Character count: 11822

Journal of Physics: Conference Series

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To cite this article: M Ariani *et al* 2020 *J. Phys.: Conf. Ser.* **1568** 012015

4th-Padjadjaran International Physics Symposium 2019 (4th-PIPS-2019) IOP Publishing
Journal of Physics: Conference Series **1568** (2020) 012015 doi:10.1088/1742-6596/1568/1/012015

Optimized core design for small long-life gas cooled fast reactors with natural uranium-thorium-blend as fuel cycle input

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Abstract. Nuclear power is the use of nuclear reactions that release nuclear energy to generate heat, which most frequently is then used in steam turbines to produce electricity. Presently, the vast majority of electricity from nuclear power is produced by nuclear fission of uranium. The alternative fuel was thorium with the key similarity is that both can absorb neutrons and transmute into fissile elements. Thorium is approximately three times as abundant as uranium in the earth's crusts, reflecting the fact that thorium has a longer half-life. However, thorium is a fertile material that could not react spontaneously. It needs to be mixed with fissile materials such as uranium or plutonium. Optimized core design and fuel management for small long-life gas cooled fast reactors (600 MWt GCFR) has been performed. The fuel core regions are subdivided into ten parts (region-1 until region-10) with the same volume in the axial direction. The fresh natural uranium-thorium blend is initially put in region-1, after one cycle of 10 years of burn-up it is shifted to region-2 and region-1 filled by fresh natural uranium-thorium blend fuel. This concept is basically applied to all regions in axial core, i.e. shifted the core of (i) region into (i+1) region after the end of 10 years burn-up cycle. For the next cycles, we will add only natural uranium-thorium blend on region-1.The calculation results show that the composition of the fresh fuel for the optimized core consists of 60% thorium-232 and 40% natural uranium.

1. Introduction

Thorium is approximately three times as abundant as uranium in the earth's crust, reflecting the fact that thorium has a longer half-life. In addition, thorium generally is present in higher concentrations (2-10%) by weight than uranium (0.1-1%) in their respective ores, making thorium retrieval much less expensive and less environmentally damaging per unit of energy extracted. Thorium (Th-232) is not itself fissile and so is not directly usable thermal reactor fuel. It is fertile and upon absorbing a neutron will transmute to uranium-233 (U-233), which is an excellent fissile fuel material. In this regard it is similar to uranium-238 (which transmutes to plutonium-239). Th-U fuel doesn't produce any transuranic elements since there is no uranium-238 being irradiated and produce harmful elements such as plutonium-239 [1]. It would be useful to combine these benefit with a long fuel cycle lifetime. This paper presents conceptual design for small long life gas cooled fast reactor with helium coolant. This reactor utilized nuclear fuel based on combine thorium fuel cycle and uranium fuel cycle. Additional uranium is still being made because it considered the criticality of the reactor. Thorium fuels therefore need a fissile material as a driver so that a burnup chain reaction can be maintained. The only fissile driver options are U-233, U-

235 or Pu-239.The Modified CANDLE (Constant Axial shape of Neutron flux, nuclide densities and power shape During Life of Energy producing reactor) is burn-up strategy needed in order to the reactor can continue its operation with fuel without enrichment and no need or fuel reprocessing plant [2]. This strategy is modification of CANDLE burn-up. The strategy can be applied to several reactors, when the infinite neutron multiplication factor of fuel element of the reactor changes along burn-up as the followings [3,4,5]. The previous study shows that Modified CANDLE concept was successfully applicable to long-life fast reactor with Natural Uranium as fuel cycle input [6,7,8]. This research was calculate and determinated the composition blend of thorium and uranium that used to continue gas cooled fast reactor with thermal power 600 MWt.

2. Design Concept

Table 1 shows design parameters and constraints for neutronic calculation. The reactor was design to operated 10 years without refueling.

Table 1. Optimization results for 600 MWt gas cooled fast reactors with Modified CANDLE

Parameter	Value/description
thermal power	600 MWt
Sub cycle length	10 years
Fuel type	Nitride(Thorium, uranium, mixed Th-U, plutonium)
Cladding type	Stainless steel
Coolant type	helium
Fuel: cladding: coolant volume fraction	65% : 10% : 25%
Axial width of each region	17 cm
Active core radial width	120 cm
Average power density	75 watt/cm^3

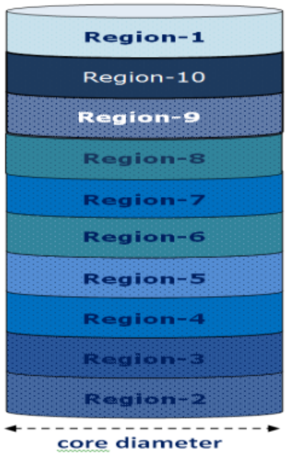

Figure 1. Distribution regions for active core

As in Figure 1, the active cylinder core was subdivided into 10 regions with the same volume in the axial direction. Each region is filled with different fuel. For the initial condition or startup operation, fuel composition for each region was presented at Table 2. Region-1 contains fresh fuel (fuel with no enrichment) that means of natural uranium (99.3% uranium-238 anf 0.7% uranium-235) and thorium-232 derived from natural mined thorium. Region-2 until Region-10 filled fuel with various composition fertile and fissile materials (see Table 2). After one cycle (10 years of burn-up) Region-1is shifted to region-2 and region-1 filled by fresh fuel. This concept is basically applied to all regions in axial core, i.e. shifted the core of (i) region into (i+1) region after the end of 10 years burn-up cycle

Table 2. The composition fuel for each region in startup condition

Name of region	Fuel composition
Region-1	Fresh fuel (no enrichment): ThN+UN
Region-2	Fuel after 10 years burnup
Region-3	Fuel after 20 years burnup
Region-4	Fuel after 30 years burnup
Region-5	Fuel after 40 years burnup
Region-6	Fuel after 50 years burnup
Region-7	Fuel after 60 years burnup
Region-8	Fuel after 70 years burnup
Region-9	Fuel after 80 years burnup
Region-10	Fuel after 90 years burnup

3. Calculation Method

The SRAC (Standard Reactor Analysis Code) is a code system for nuclear reactor analysis and design. Neutronic performance for analyzed the neutron aspect of this reactor core was examine by using of SRAC code system with JENDL-3.2 nuclear data library. It is composed of neutron cross section libraries and auxiliary processing codes, neutron spectrum routines, a variety of transport, 1-D, 2-D and 3-D diffusion routines, dynamic parameters and cell burn-up routines [9]. Cell calculation for fuel composition using collision probability methods applied for 1-D cylindrical fuel pin type. Multi dimensional diffusion code are integrated into the system to calculate 2D-Cylinder core (R-Z Geometry). The parameters survey used to analyze results of the design include: conversion ratio and k-eff (effective neutron multiplication factor) for 1 cycle operation.

This research investigated 11 core design with different fresh fuel loaded to Region-1. Each type of fuel differs according to the ratio of composition between thorium and uranium fuel. Table 3 presents composition for fresh fuel for each core design. The first core design used only natural uranium nitride loaded to Region-1. Second core design used only thorium-232 (nitride) loaded as fresh fuel. The next core design used fuel with varying consentration of thorium and uranium.

Table 3. Fresh Fuel input composition for specific core design

Core design	Fuel type	Composition Atomic number density N(ThN):N(UN)	Symbol for fuel cycle
Core-1	Nat.uranium nitride (UN)	0% : 100%	U-cycle
Core-2	Thorium Nitride (ThN)	100% : 0%	Th-cycle
Core-3	(ThN-UN)blend type-1	90% : 10%	ThU(90-10)%
Core-4	(ThN-UN)blend type-2	80% : 20%	ThU(80-20)%
Core-5	(ThN-UN)blend type-3	70% : 30%	ThU(70-30)%
Core-6	(ThN-UN)blend type-4	60% : 40%	ThU(60-40)%
Core-7	(ThN-UN)blend type-5	50% : 50%	ThU(50-50)%
Core-8	(ThN-UN)blend type-6	40% : 60%	ThU(40-60)%
Core-9	(ThN-UN)blend type-7	30% : 70%	ThU(30-70)%
Core-10	(ThN-UN)blend type-8	20% : 80%	ThU(20-80)%
Core-11	(ThN-UN)blend type-9	10% : 90%	ThU(10-90)%

4. Results and Discussion

One measure of a reactor's performance is the conversion ratio, defined as the ratio of production rate to depletion rate of fissile nuclides. As long as there is any amount of a fertile material within the neutron flux of the reactor, some new fissile material is always created. When the conversion ratio is greater than 1, it is often called the "breeding ratio". Figure 2 presents the result of neutron flux calculation for uranium and thorium fuel cycle.

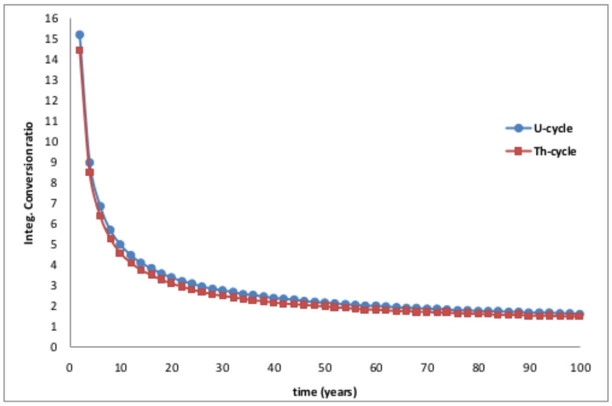

Figure 2. Comparison of Integral conversion ratio for natural uranium cycle and thorium-232 cycle

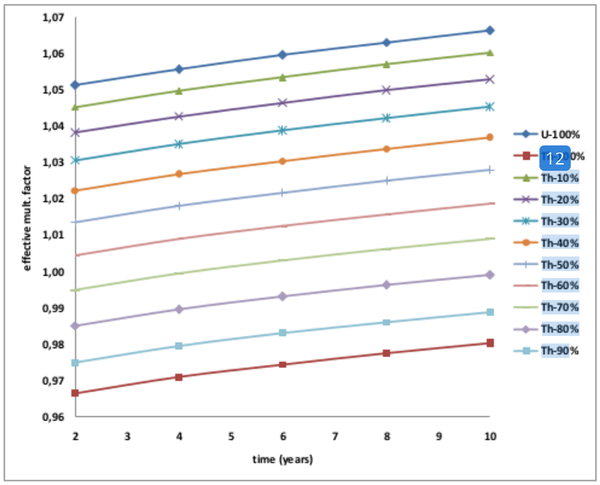

Figure 3. Effective neutron multiplication factor for 11 core design

Conversion ratio value for natural uranium is relatively higher compared to thorium-232. Breeding ratio for both the natural uranium and thorium-232 greater than 1 so the breeding is possible in fast parts of the neutron spectrum.

The results of cell calculation for uranium and thorium fuel cycle integrated to core calculation with Modified CANDLE burn-up strategy are presented. Criticality indicates wether a reactor is operating or not. There are two terms related to criticality: supercritical and subcritical, which are both also normal and essential to proper nuclear power generation. Figure 3 shows comparison of criticality condition for 11 core design with different fuel composition. When k-eff = 1 (critical): every fission causes an average of one more fission, leading to a fission (and power) level that is constant. Nuclear power plants operate with k-eff = 1 unless the power level is being increased or decreased.

Table 4. The excess reactivity value for each reactor core design

Name core	fuel cycle	Average excess reactivity(%)
Core-1	U-cycle	5,59
Core-2	Th-cycle	-2,69
Core-3	ThU(90-10)%	-1,79
Core-4	ThU(80-20)%	-0,75
Core-5	ThU(70-30)%	0,25
Core-6	ThU(60-40)%	1,19
Core-7	ThU(50-50)%	2,08
Core-8	ThU(40-60)%	2,91
Core-9	ThU(30-70)%	3,70
Core-10	ThU(20-80)%	4,40
Core-11	ThU(10-90)%	5,05

The excess reactivity in Table 4 is defined as the reactivity of a core if all control poisons (control rods, burnable absorbers, boric acid) were instantaneously eliminated from the core. Large excess reactivities are undesirable because they require large amounts of neutron poisons to be present in the core to compensate for them. Large excess reactivities are not economical due to very high accumulation of fission products.When the k-eff=1 then excess reactivity value was 0. Based on these criteria the core optimization was determined by the k-eff value which is close to 1. Core-6 that use (Th-U) blend type-4 for fresh fuel loaded to Region-1 can achieve that. Average excess reactivity (1.19%) smaller compare to the other cores design.

5. Conclusion

Breeding ratio for both the natural uranium and thorium-232 greater than unity implies that for every fission reaction, more than one fissile atom can be generated, and the fuel can be bred from non-fissile material. The composition of the fresh fuel for the optimized core consists of 60% thorium-232 (ThN) and 40% natural uranium (UN). This reactor can operate for 10 years without refueling.

References

[1] Kooyman T, Buiron L 2016 *Annals of Nuclear Energy* **92** 61
[2] Su'ud Z, Sekimoto H 2010 *International Journal of Nuclear Energy Science and Technology* **5** 347
[3] Sekimoto, H, Ryu K, Yoshimura Y 2001 *Nuclear Science Engineering* **139** 306
[4] Sekimoto H, Yan M Y, *Annals of Nuclear Energy* **35** 18
[5] Tsuyoshi Ohkawa, Sinsuke Nakayama, Hiroshi Sekimoto 2012 *Energy Conversion and Management* **53** 182
[6] Ariani M, Su Z, Monado F, Waris A, Arif I, Sekimoto H 2013 *Applid Mechanics and materials* **260** 307
[7] Su'ud Z, Sekimoto H 2013 *Annals of Nuclear Energy* **54**, 58
[8] Su'ud Z, Miftasani F, Ilham, Sarah A, Ariani M, Sekimoto H, Waris A, Sidik P, *Energy Procedia*, **131** pp 6
[9] Okumura K, Kaneko K, Tsuchihashi K, 1996 SRAC95 General Purpose Neutronics Code System, *JAERI-Data/Code* 96-015, Japan Atomic Energy Research Institute, Japan

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