NEUTRONIC ANALYSIS OF DETERMINATION OF FUEL CONFIGURATION FOR HOMOGENEOUS TRIGA 2000 NEW CORE

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Abstract *A neutronic analysis has been carried out to determine the configuration of fuel for the homogeneous TRIGA 2000 Reactor new core. This analysis is carried out to get the most optimal configuration scenario if all fuels used are fresh fuel by meeting the parameters in accordance with safety requirements where; shutdown margin ≥ $-0.5; Axial and radial Power Peaking Factor is less than 1.25 and 1.60. There are three types of homogenous core in this study that consist of three types of fuel elements; 8.5-20; 12.20 and 20-20. Method that is used in this study is count each fuel element and scenario with MCNP5 codes. Base on configuration scenarios that have been studied, we concluded that homogeneous core with 90 fuel elements with 12-20 type is the optimum one with k-eff= 1.03342.*

INTRODUCTION

TRIGA 2000 reactor is the first research reactor in Indonesia. As the name implies, this reactor is used for training, research, and isotope production. To support the interests of the utilization of reactors, a reactor maintenance program needs to be prepared. One of the reactor maintenance programs is to carry out terrace management that aims to get optimal reactivity by using the amount of fuel as efficiently as possible and must also pay attention to some safety parameters listed in the reactor's operating conditions (BKO). That way, the optimal terrace must be safe and safe when the terrace is operated.

The value of the terrace reactivity will go down because of the operation and addition of the burn-up value of the fuel element so that the power generated by the reactor will be small even though the position of the control rod is maximum. Therefore, it is necessary to do terrace management, either with reshuffling or refueling.

The basic principle of terrace management is to achieve reactivity value with other patio parameters, such as shutdown margin and axial and radial peak factors; Zoairia Idris Lyric et al. [1] Analyzed Core Excess Reactivity Calculation for the Terrak Triga Mark II Power of 3 MW. The configuration used is a uniform terrace configuration. The simulation uses the MVP system code with Jendl 3.3 as a nuclide data library. Of the three configuration scenarios conducted, a 10,825 core excess value was obtained: 10,227 and 10,040. Of the three configuration scenarios conducted, a radial peak factor value of 1.67, 1,65, and 1.72. At the same time, the margin shutdown values obtained are 7,047, 7,032, and 7,411.

Ravnik and Zagar [2] studied two types of terraces: uniform terraces and mixed terraces. The mixture terrace is fuel from various types, namely types 8.5, 12, and 20. Analysis on the uniform terrace produces a radial peak factor value of 1.6, while the mixture terrace produces a higher value of 2.00. The configuration in this study was carried out based on the amount of critical mass of fuel. Furthermore, neutronic calculations are carried out assuming that all fuel used is fresh fuel (fresh fuel).

The analysis conducted in this study was a new terrace configuration scenario in the Triga 2000 reactor terrace conditions. For each scenario, the terrace was conditioned uniformly. In every scenario, only one fuel type is used, namely type 8.5-20, 12-20, or 20-20. Type 8.5-20 is a fuel with a uranium composition of 8.5% of the total fuel. Type 12-20 is a fuel with a 12% uranium composition of the total fuel.

In contrast, the 20-20 type is a fuel with a uranium composition of 20 % of the total fuel. Enrichment of the three fuel types is the same, namely 19.97 %. The position of irradiation facilities is assumed to be the same as the existing facilities. This study's scenario adheres to the rules for preparing fuel configurations based on the burnt faction and mass density.

The purpose of this study is to find out the optimal 2000 triga 2000 reactor configuration scenario option. Safety parameters must be considered: core excess, shutdown margin, fulfillment of one stuck rod criteria, and axial and radial peak factors.

Theory

In preparing a new terrace scenario, paying attention to the parameters of terrace safety is necessary. These parameters are determined based on the results of MCNP5 calculations, among others [3], including reactivity parameters:

1. The reactivity of the terrace is calculated based on the K-Eff value for the simulation, where all control rods are in the maximum withdrawal position. From the K-EFF value, the reactivity can be calculated by the formulation:

   $$\rho_{ce} = \left(\frac{k_{eff}-1}{k_{eff}}\right)\frac{1}{\beta_{eff}} \qquad (1)$$

   With:
   ρ_{ce} = excess core reactivity;
   k_{eff} = effective multiplicity factor;
   β_{eff} = beta effective factor.
2. Shut down Core Reactivity, calculated based on the K-Eff value for simulations where all control rods are in the terrace. From the K-EFF value, the reactivity can be calculated by the formulation:

   $$\rho_{sm} = \left(\frac{k_{eff(0)}-1}{k_{eff(0)}}\right)\frac{1}{\beta_{eff(0)}} \qquad (2)$$

   With:
   ρ_{sm} = Shut down Core Reactivity at 0 position safety control rod;
   $k_{eff(0)}$ = effective multiplicity factor at 0 position safety control rod;
   $\beta_{eff(0)}$ = beta effective factor at 0 position safety control rod;.
3. Total reactivity, calculated based on the difference between more terrace reactivity and extinguished reactivity:

   $$\rho_{tot} = \rho_{ce} - \rho_{sm} \qquad (3)$$

   With:
   ρ_{tot} = Total Core Reactivity;
   ρ_{ce} = excess core reactivity;
   ρ_{sm} = Shut down Core Reactivity.
4. Shutdown margin, calculated based on the value of K-Eff for simulation in conditions if there is one control of control with the largest reactivity value (one stuck rod criteria). The reactivity is calculated with the same formulation as in points 1, 2, and 3. For determining the shutdown margin, it is necessary to simulate the condition of one control of the controls; in this case, there are 5 (five) times the scenario of the simulation event; for each of them, the reactivity is calculated, And one of the largest reactivity values that will be the margin shutdown value of the configuration scenario.
5. Control Rod Worth Each control rod, basically the amount of terrace reactivity caused by each control rod's withdrawal relative to its outstanding condition. In this case, the control rod worth each control rod can be calculated from the difference in the value of terrace reactivity in each condition of one stuck rod with a fixed reactivity:

   $$\rho_{CRW} = \rho_{\text{one stuck rod}} - \rho_{sm} \qquad (4)$$

   With:
   ρ_{CRW} = control rod worth;
   $\rho_{one\ stuck\ rod}$ = Core Reactivity on stucked safety control rod;
   ρ_{sm} = Shut down Core Reactivity.

6. Total Rod Worth Control can be calculated from the sum of the entire control of the control rod control.

The peak power factor (FPD) is the relationship between neutronic analysis and thermohydraulic from a reactor terrace defined in maximum power and produced locally in the terrace. The peak power factor commonly used in the Triga reactor is [7]:

1. Peak Factor Hot Rod FHR Power;
2. The peak factor of axial power, FZ;
3. Radial Power Power Factors, FR;
4. Popal Factors Total power, ftot.

To calculate this value from the results of the MCNP output can be done as follows: By taking the filling of a reactor operation modeling on power, P KW:

$$[P_{MeV}]_{segmen} = (P_{F7})_{segmen} \times m_{segmen} \qquad (5)$$

$$[P]_{MeV} = \sum_{i=1}^{15}[P_{MeV}]_{segmen} \qquad (6)$$

$$[P_{kW}]_{segmen} = \frac{[P_{MeV}]_{segmen}}{\sum_{i=1}^{NEB}(P_{MeV})_i} \times P\ [kW] \qquad (7)$$

$$P_{kW} = \sum_{i=1}^{15}[P_{kW}]_{segmen} \qquad (8)$$

With:
PMeV = power on MeV;
PkW = power on kW;
msegmen = fuel segment mass.

PKW is the power produced by every fuel. From the calculation results, data in equation (6) can then be continued in determining the axial peak factor and total power peak factor:

$$f_{z_i} = \frac{([P_{kW}]_{segmen})_{max}}{\overline{[P_{kW}]_{segmen}}} \qquad (9)$$

$$\overline{[P_{kW}]_{segmen}} = \frac{\sum_{i=1}^{15}[P_{kW}]_{segmen}}{15} \qquad (10)$$

With:

$([P_{kW}]_{segmen})_{max}$ = Max fuel power on axial segment;

$\overline{[P_{kW}]_{segmen}}$ = average fuel power on axial segment;

Then, from the formulation above, it can be determined the axial peak factor of the average terrace axial power and the maximum axial peak power factor with the formulation:

$$\overline{F}_z = \frac{\sum_{i=1}^{N} f_{z_i}}{N} \qquad (11)$$

$$[F_z]\, max(_{z_{imax}} \qquad (12)$$

dengan,

$\overline{F_z}$ = average axial core peak power factor;

$[F_z]_{max}$ = max axial core peak power factor;

Then, the peak factor of radial power can be calculated using the following formulations:

1. The average core power; $(P_{rod})_{av} = \frac{P}{N_{EB}}$ with P as the reactor power, and N_{EB} is the number of fuel elements in the terrace.
2. The peak factor of the radial power can be calculated from $f_{radial} = \frac{(p_{kW})_{max}}{(p_{kW})_{av}}$ with $(p_{kW})_{max}$ as the maximum power meeting;
3. $\frac{(P_{kW})_{max}}{V_{rod}}$ and $(p_{kW})_{av}$ is an average power meeting; $\frac{(P_{kW})_{av}}{V_{rod}}$.

For (PKW), Max is determined from the power of the hottest burning elements on the terrace. This value can be obtained from the calculation results with equation (7). The N_Eb is the number of fuel elements in the terrace [6]. The Safety Analysis report of the 2000 Triga reactor states that the requirements for the margin shutdown value ≥ $ -0.5; Axial FPD and FPD radial not exceeding 1,30 dan 1,65 [11].

METHODS

This study calculated the terrace critical calculation using the MCNP5 program code. Calculated critical parameters are the value of effective multiplication factors, core excess, one stuck rod criteria fulfillment, and shutdown margin. The reactor terrace geometry refers to the current reactor terrace without including the components of irradiation facilities outside the terrace. Figure 1 shows the geometry of the core Triga 2000 Bandung reactor.

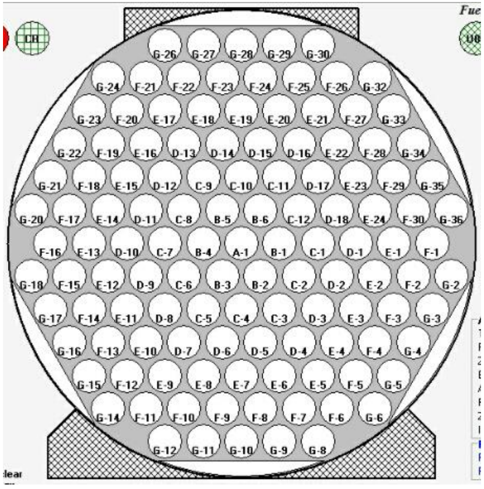

Figure 1. Core configuration of Bandung TRIGA 2000 reactor.

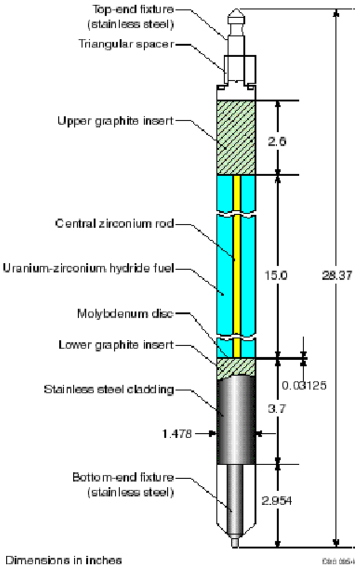

Figure 2. Fuel configuration of Bandung TRIGA 2000 reactor.

In this activity, the analysis was carried out simulatively using MCNP5, bridged by the Mobccs and Triga-MCNP applications as an auxiliary application in modifying the input to meet the latest terrace conditions. Then, the extraction activities of some MCNP5 output results, such as Tally F4, are used for determining neutron flux, and Tally F7 for determining power fluxes.

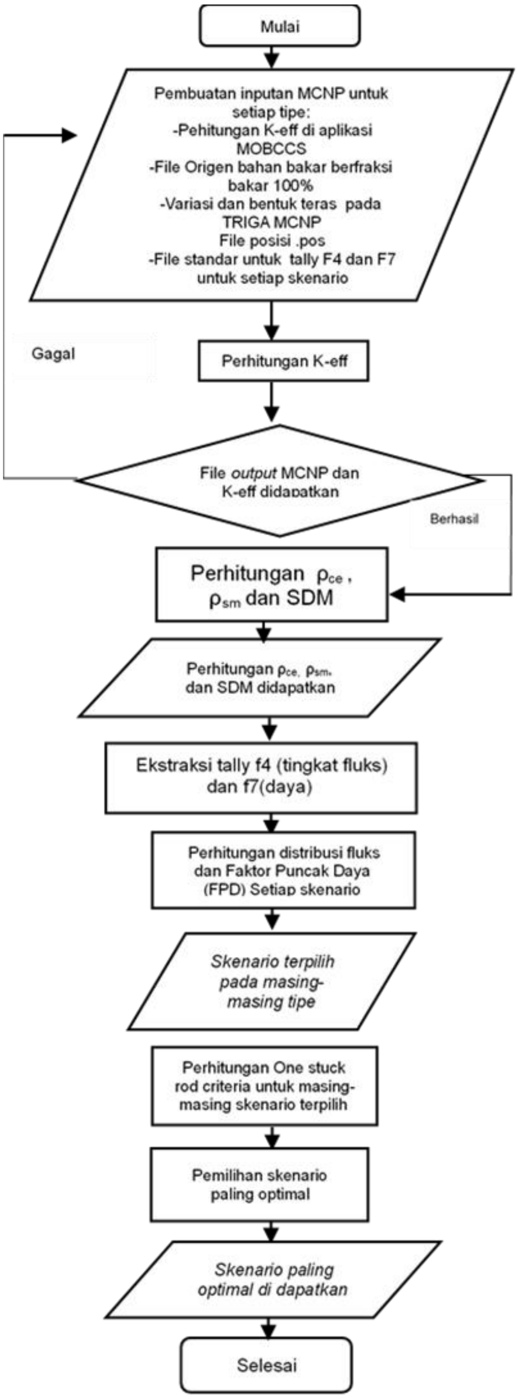

Figure 3. Research Flowchart

Fuel in Figure 2 is the default fuel from the Triga 2000 reactor produced by General Atomic. This fuel is cylindrical with a UZRH chemical composition. Enrichment for each fuel is at most 20 % of this by the basic design of this reactor. The analysis and calculation steps are carried out as shown in Figure 3

Some configuration scenarios are carried out with details of the name scenario and the amount of fuel used as follows:

Table 1. new core scenario with similar fuel

No.	Scenario	Number of fuel used
1	8,5 A	112
2	8,5 B	102
3	8,5 C	100
4	8,5 D	98
5	8,5 E	96
6	8,5 F	92
7	8,5 G	90
8	8,5 H	88
9	8,5 I	86
10	12 A	112
11	12 B	102
12	12 C	92
13	12 D	90
14	12 E	88
15	12 F	86
16	12 G	84
17	12 H	82
18	12 I	72
19	20 A	112
20	20 B	102
21	20 C	92
22	20 D	90
23	20 E	88
24	20 F	86
25	20 G	84
26	20 H	82
27	20 I	72

RESULTS AND DISCUSSION

This study analyzed several fresh fuel configuration scenarios to form an optimal new terrace. The scenario carried out is based on changes in the fuel used. From several scenarios that are simulated, and obtained data and the following discussion:

Table 2. Critical Value of New core Scenarios with Fuel Type 8.5-20

Scenario	k-eff	
	Fully up CR	*Fully down CR*
8,5 A	1.07493	0.97471
8,5 B	1.01718	0.92188
8,5 C	0.99952	0.90819
8,5 D	0.98730	0.89929
8,5 E	0.97834	0.89303
8,5 F	0.97201	0.88719
8,5 G	0.94981	0.87305
8,5 H	0.93179	0.85832
8,5 I	0.91694	0.84307

Table 3. Peak Power factor (PPF) axial and radial of new core Scenarios with Fuel Type 8.5-20

Scenario	PPF	
	Axial	Radial
8,5 A	1,266	1,210
8,5 B	1,275	1,279
8,5 C	1,274	1,313
8,5 D	1,269	1,333
8,5 E	1,275	1,370
8,5 F	1,269	1,342
8,5 G	1,267	1,290
8,5 H	1,267	1,290
8,5 I	1,269	1,492

Table 2 shows the critical value produced from a new terrace scenario that uses fresh fuel type 8.5-20.

This table also shows that the scenario of 8.5C s.d. 8.5i cannot be used because, with the configuration used, the reactor does not reach critical from the value of effective multiplication factors that are less than 1,000. Therefore, only two scenarios of the 8.5-20 types are left, namely the 8.5A and 8.5B scenarios. Scenario 8.5A, the reactor reaches critical with the value of K-Eff = 1,07493. When all control stems are lowered to position 0, the reactor can reach subcritis with the value of K-Eff = 0.97471. In the 8.5B scenario, the reactor reached critical with the value of K-Eff = 1,01718. When all control rods are lowered to position 0, the reactor can reach the subcritis with the value of K-Eff = 0.92188.

The axial peak factor value for the two scenarios can be seen in Table 3, which is 1,266 for the 8.5A scenario and 1,275 for the 8.5B scenario, which meets the requirements in LAK. While the radial peak factor value for the two scenarios is 1,210 for the 8.5A scenario and 1,279 for the 8.5B scenario, it already meets the required value in LAK. From the two selected scenarios, a simulation of the reactivity calculation is carried out in one stuck rod criterion (one stuck rod criterion).

Table 4. one stuck rod criteria ctesting of new core Scenarios with Fuel Type 8.5-20

	Konfigurasi 8,5A			
	Stuckrod	*k--eff*	*Δk/k*	*Reactivity ($)*
112 Fuels	*shim* 1	0.9997	-0.0003	-0.0403
	shim 2	0.9996	-0.0004	-0.0570
	shim 3	1.0011	0.0011	0.1471
	shim 4	0.9974	-0.0026	-0.3662
	shim 5	0.9963	-0.0037	-0.5200
	Konfigurasi 8,5B			
	Stuckrod	*k--eff*	*Δk/k*	*Reactivity ($)*
102 Fuels	*shim* 1	0.9401	-0.0637	-8.8464
	shim 2	0.9510	-0.0515	-7.1531
	shim 3	0.9423	-0.0613	-8.5109
	shim 4	0.9473	-0.0556	-7.7266
	shim 5	0.9455	-0.0577	-8.0089

Table 4 shows that the 8.5A configuration does not meet the value of one stuck rod criteria because when the SHIM 3 control rod is stuck, the K-Eff value is still above one. Alternatively, it can be interpreted that when the SHIM 1 control stem is stuck, the reactor cannot go out. In addition, the value of the shutdown margin also does not meet the requirements of LAK. Therefore, the scenario selected for a new terrace with a type of 8.5-20 uniform fuel is an 8.5B scenario.

Table 5 shows the critical value produced from the new terrace scenario using fresh fuel type 12-20

Table 5. Critical Value of New core Scenarios with Fuel Type 12-20

Scena rio	k-eff	
	Fully up CR	*Fully down CR*
12 A	1.15780	1.06692
12 B	1.10230	1.00498
12 C	1.05569	0.96800
12 D	1.03342	0.95207
12 E	1.01450	0.93779
12 F	1.00199	0.92269
12 G	0.99194	0.91102
12 H	0.98400	0.89986
12 I	0.90063	0.83023

Table 6. Peak Power factor (PPF) axial and radial of new core Scenarios with Fuel Type 12-20

Skenario	FPD	
	Axial	Radial
12 A	1,259	1,209
12 B	1,263	1,331
12 C	1,264	1,343
12 D	1,263	1,315
12 E	1,265	1,489
12 F	1,265	1,343
12 G	1,263	1,369
12 H	1,266	1,344
12 I	1,265	1,346

For these four scenarios, the value of the axial and radial peak factors produced still meets the requirements outlined in LAK, as indicated by Table 6. Of the four selected scenarios, a simulation of reactivity calculation is carried out in one stuck rod criteria (one stuck rod criteria).

Referring to Table 6, the 12C configuration does not meet the criteria for one stuck rod for the SHIM 2 control rod. Among the three remaining scenarios, the scenario selected for a new terrace with uniform fuel type 12-20 is a 12D scenario with a K-Eff value = 1,03342, Axial FPD = 1,263, and FPD Radial value = 1,315. The 12D scenario K-EFF value is higher than the K-Eff value of the 12E and 12F scenarios, so it is expected that the reactivity of the terrace can be maintained longer

Table 7. one stuck rod criteria ctesting of new core Scenarios with Fuel Type 12-20

	12C Configuration			
	Stuckrod	*k-eff*	*Δk/k*	*Reactivity ($)*
92 Fuels	*shim* 1	0.98608	-0.01412	-1.96063
	shim 2	1.00678	0.00673	0.93533
	shim 3	0.98857	-0.01156	-1.60585
	shim 4	0.97884	-0.02162	-3.00242
	shim 5	0.97775	-0.02276	-3.16060
	12D Configuration			
	Stuckrod	*k-eff*	*Δk/k*	*Reactivity ($)*
90 Fuels	*shim* 1	0.91333	-0.09489	-13.17979
	shim 2	0.93138	-0.07368	-10.23273
	shim 3	0.91438	-0.09364	-13.00517
	shim 4	0.92319	-0.08320	-11.55564
	shim 5	0.92194	-0.08467	-11.75962
	12E Configuration			
	Stuckrod	*k-eff*	*Δk/k*	*Reactivity ($)*
88 Fuels	*shim* 1	0.85141	-0.17452	-24.239
	shim 2	0.85236	-0.17321	-24.057
	shim 3	0.84161	-0.18820	-26.139
	shim 4	0.84465	-0.18392	-25.545
	shim 5	0.84446	-0.18419	-25.582
	12F Configuration			
	Stuckrod	*k-eff*	*Δk/k*	*Reactivity ($)*
86 Fuels	*shim* 1	0.93547	-0.06898	-9.58075
	shim 2	0.95665	-0.04531	-6.29366
	shim 3	0.93724	-0.06696	-9.30036
	shim 4	0.93796	-0.06614	-9.18660
	shim 5	0.93674	-0.06753	-9.37946

Table 8. Critical Value of New core Scenarios with Fuel Type 20-20

Scenario	k-eff	
	Fully up CR	*Fully down CR*
20 A	1.13037	1.04041
20 B	1.09230	1.00317
20 C	1.05415	0.97073
20 D	1.03453	0.95600
20 E	1.02053	0.94465
20 F	1.01334	0.93525
20 G	1.00548	0.92787
20 H	0.99960	0.91844
20 I	0.93176	0.86045

Table 9. Peak Power factor (PPF) axial and radial of new core Scenarios with Fuel Type 20-20

Skenario	FPD	
	Axial	Radial
20 A	1,259	1,221
20 B	1,246	1,421
20 C	1,249	1,408
20 D	1,252	1,410
20 E	1,256	1,366
20 F	1,249	1,362
20 G	1,257	1,350
20 H	1,251	1,408
20 I	1,256	1,590

Table 8 shows the critical value produced from a new terrace scenario that uses fresh fuel type 20-20. This table shows that the 20H and 20i scenarios cannot be used because, with the configuration used, the reactor does not reach critical. While the 20A and 20B scenarios can also not be used when the entire control rod is reduced to position 0, the reactor cannot reach the subcritical condition or be shut down. 20C, 20D, 20E, 20F, and 20G scenarios can be used because the reactor can be critical, and when all control rods are reduced to position 0, reactors can reach subcritis/shutdown.

For these five scenarios, the value of the axial and radial peak factors produced can still meet the requirements outlined in LAK, as indicated by Table 9. Of the five selected scenarios, a simulation of reactivity calculation is carried out in one stuck rod criteria (one stuck rod criteria).

Referring to Table 10, the 20C configuration does not meet the criteria of one stuck rod for the SHIM 2 control rod because at the time Shim 2 is stuck, the value of the multiplication factor is more than 1,000, so the reactor that should be in a condition of extinguished is critical. Among the four remaining scenarios, the scenario selected for a new terrace with a uniform fuel type 20-20 is a 20D scenario with a K-Eff value = 1,03453, Axial FPD = 1,252, and FPD Radial value = 1,410. The K-EFF value of the 20D scenario is higher than the K-Eff values of the 20E, 20F, and 20G scenarios, so it is expected that the reactivity of the terrace can be maintained longer.

Table 10. one stuck rod criteria ctesting of new core Scenarios with Fuel Type 12-20

	20C Configuration			
	Stuckrod	*k-eff*	*Δk/k*	*Reactivity ($)*
92 Fuels	*shim* 1	0.98928	-0.01084	-1.50502
	shim 2	1.00228	0.00227	0.31595
	shim 3	0.99092	-0.00916	-1.27267
	shim 4	0.98272	-0.01758	-2.44220
	shim 5	0.98131	-0.01905	-2.64527
	20D Configuration			
	Stuckrod	*k-eff*	*Δk/k*	*Reactivity ($)*
90 Fuels	*shim* 1	0.97203	-0.02877	-3.99650
	shim 2	0.98763	-0.01252	-1.73957
	shim 3	0.97327	-0.02746	-3.81446
	shim 4	0.96713	-0.03399	-4.72044
	shim 5	0.96672	-0.03443	-4.78135
	20E Configuration			
	Stuckrod	*k-eff*	*Δk/k*	*Reactivity ($)*
88 Fuels	*shim* 1	0.95953	-0.04218	-5.85790
	shim 2	0.97444	-0.02623	-3.64312
	shim 3	0.96132	-0.04024	-5.58838
	shim 4	0.95773	-0.04414	-6.12995
	shim 5	0.95711	-0.04481	-6.22389
	20F Configuration			
	Stuckrod	*k-eff*	*Δk/k*	*Reactivity ($)*
86 Fuels	*shim* 1	0.94956	-0.05312	-7.37769
	shim 2	0.96490	-0.03638	-5.05234
	shim 3	0.95115	-0.05136	-7.13318
	shim 4	0.95068	-0.05188	-7.20537
	shim 5	0.94973	-0.05293	-7.35150
	20G Configuration			
	Stuckrod	*k-eff*	*Δk/k*	*Reactivity ($)*
86 Fuels	*shim* 1	0.94188	-0.06171	-8.57033
	shim 2	0.95550	-0.04657	-6.46840
	shim 3	0.94328	-0.06013	-8.35147
	shim 4	0.94662	-0.05639	-7.83196
	shim 5	0.94376	-0.05959	-8.27659

CONCLUSION

From the whole scenario simulated for the new terrace configuration of the 2000 Triga reactor with uniform fuel, it can be seen that the 12D scenario with a K-Eff value = 1,03342 requires less fuel than the 8.5B scenario that uses 102 fuel with a value K-Eff = 1,01718. Compared to the 20D scenario, the fuel needed is the same. Considering the price of fuel type 20-20 is higher than that of fuel type 12-20, it is determined that the best scenario is 12D.

When viewed from the fulfillment of the values of safety parameters, the 12D scenario has a critical critique of 1,03342 when the entire control rod is in the maximum position. It can be interpreted that the terrace has a reactivity of more than 0.03342. The second safety parameter, shutdown margin, is filled with a value of -13.17979 $. The reactor can go out in the position of the entire control stem at point 0. The axial and radial peak factors of the 12D scenario are 1,263 and 1,315. The entire safety parameter owned by the 12D scenario has met the requirements in LAK. These circumstances underlie the choice of the 12D scenario as the optimal scenario.

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