2021 International Nuclear Atlantic Conference – INAC 2021
Virtual meeting, Brazil, November 29 – December 2, 2021

ISBN: 978-65-594-1256-3
9 786559 412563

Initial Criticality of the New Core with Plate-Type Fuel Elements of the Nuclear Reactor IPEN/MB-01

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1. Introduction

The IPEN/MB-01 reactor is the result of a close collaboration between the years 1983-1988 of the National Nuclear Energy Commission through the Nuclear and Energy Research Institute (IPEN) and the Special Projects Coordination of the Ministry of the Navy (COPESP), currently the Navy Technological Center in São Paulo (CTMSP). Researchers and engineers from IPEN and COPESP participated in the design, construction, criticalization and commissioning of the first nucleus of the so-called Critical Unit at the time. The Project developed by IPEN and COPESP also counted on the collaboration of the Institute of Nuclear Engineering (IEN) in the development of the reactor's nuclear control instrumentation. The first standard core consisted of an array of 680 combustible rods, with each combustible rod containing 52 UO2 pellets enriched to 4.3% U-235 arranged in a configuration that represented an array of a rectangular parallelogram of 28x26 coating combustible rods stainless steel 304 L. The fuel rods were fixed on 3 matrix plates (upper, intermediate and lower) of 30x30 whose distance between holes (pitch) was 15 mm. The moderator used as well as the reflector were light water. Its first criticality occurred at 15 hours and 35 minutes on November 9, 1988 and for 30 years (1988-2018) the reactor carried out the most diverse experiments in the field of Reactor Physics [1].

The original idea of the IPEN/MB-01 reactor is to test several reactor cores, but with scarce resources in the nuclear area over the years the first core representing 4 fuel elements of a PWR reactor, a first idea of a nuclear core with propulsion naval that core became the only one over 30 years. With the Project that started in 2008 of the Brazilian Multipurpose Reactor (RMB) the idea came up in 2013 to replace the old core with the future core of the RMB reactor. The project consisted of the total removal of the old core of fuel pin rods and their matrix plates and adaptation of the new core with plate-like fuel elements, in addition to the support matrix plate that receives the fuel elements, their heavy water reflector boxes and all their new fixation in the trusses with the mission of supporting the entire structure.

The new plate fuel rods were designed by the Nuclear Engineering Center (CEENG) and its components were manufactured and assembled at the Nuclear Fuel Center (CECON). The exception was the nozzle, side support plates, lifting axle, comb and screws machined and supplied to CECON by Brazil's Nuclear Industries (INB).

The objective of this second 5x4 array core with plate type fuel elements is to facilitate the licensing of the future core of the RMB reactor, through the validation of the calculation methodology and nuclear data used in the project. Obviously, it will also be used extensively in the teaching, academic and training function. The reactor operation group IPEN/MB-01 (SEORI) chose to make the criticality prediction of the control rods from the counts of the reactor's starting channels, B-10 detectors, obtained from the fixation of two bars of control, BC1 and BC4 at critical position already defined by neutron calculation for the 4 control rods equally removed from the core.

2. Methodology

The methodology for obtaining the critical predictions of control bars, after having completed the complete loading of fuel elements in the reactor core [2,3] in February 2020, was to use the inverse neutron multiplication curve (1/M) as a function of the parameter that will cause the criticality of the new nucleus, in this case the positions equally removed from the control rods BC2 and BC3. Through extrapolating of two points by different position of BC2=BC3 then will have two new points obtained of the straight lines extrapolated to zero, when then the multiplication of the neutrons will be zero (ratio of the counts for each of the start channels relative BC2=BC3 of the new withdrawn positions) . The 1/M =0 with BC2=BC3 withdrawal position tends to infinity for having reached the condition called critical position. For this purpose, the BC1 and BC4 control rods were kept fixed, equally retained at 64.23% of the active length of 615 mm. These positions were estimated based on the neutron calculation MCNP 5 [4] and served as an initial estimate of the critical position of the 4 control bars according to the operational procedure previously approved by DRS-CNEN [5]. Table I shows the average counts of the starting channels 1,2 and 9, C1, C2 and C9, respectively, obtained for each configuration of the control bars BC2 and BC3 equally removed from the core, as well as the average temperature of the moderator obtained by 7 thermocouples positioned inside the core.

The Multiplication inverse factor (1/M) is obtained from the ratio of the C0 reference count obtained from the same positioning of the positions of bars BC1 and BC4, kept fixed at 64.23% taken from the active core and the control rods fully inserted at BC2=BC3, that is, initially 0% withdrawn. For each count obtained for another positions of control rods BC2 and BC3 (i=1..., n) withdrawn are acquiring data of counting how showed in equation (1).

$$(1/M) = C_0/Cn \qquad (1)$$

Where n is the position of the BC2 and BC3 control rods removed in percent from the active core (615 mm) along the various steps of the control rods removal and C0 the initial average reference count (C1, C2 and C9) with BC1=BC4=64.23 % and BC2= BC3=0%. Average counts of 10 acquisition values of reactor start channels 1,2 and 9, B-10 pulse type proportional detectors.

Once obtained the inverse of 1/M multiplication for the three starting channels, 1,2 and 9, as a function of the neutron multiplication occurred between the reference situation with the BC2 and BC3 bars fully inserted inside the nucleus and situation (new step) with the two control bars BC2=BC3 removed a certain of step new percentage, the aforementioned values are plotted, where 1/M is in the ordinate and the percentage control rods removed from the active nucleus are in the abscissa. Joining these two points and extrapolating the line, we obtain 1/M=0, that is, the estimated criticality condition of the control bars BC2 = BC3. As we have 3 critical position values given by the 3 starting channels, the criticalization procedure predicts that the smallest withdrawn bar value is conservatively chosen which corresponds to the smallest reactivity value entered in the system and the next advance step of the new step will be correspond to 2/3 of this advance, option more conservative.

The results obtained in the steps that correspond to the removal of control bars 2 and 3 from the active core of the IPEN/MB-01 reactor can be seen in table I.The operating procedure consisted of the following steps:

1- Completion of the initial reactor checklist with all the procedures necessary for its safe criticality. We can mention as the most important from an operational point of view the insertion of the neutron source in the lower base of the moderator tank in order to sensitize the starting channels, the make closing the valves of the moderating tank and later filling it with water;
2- Through the cooling machines of the moderator (Chiller) the moderator temperature is stabilized between

20 and 21 degrees Celsius;

3- Measure the reference counts of the starting channels 1,2 and 9. For this, the control bars BC1 and BC4 arranged diagonally in the core in 64.23% are removed, this value calculated by the MCNP code 5 as critical for removed the 4 control rods. The BC2 and BC3 control bars are kept inserted inside the core;

4- Once the average reference counts were obtained, 10% of the control rods were initially removed in steps, as shown in Table I with the corresponding values of the inverse of the multiplication of the neutrons. After each step of removing bars BC2 and BC3 the corresponding values were inserted in a linear graph;

5- Extrapolation of the data referring to the last 2 steps of removing control rods to the zero value of 1/M for the values coming from the 3 starting channels, obtaining 3 predictions of critical positions of bars for BC2=BC3;

6- Definition of the advance percentage of bar removal for BC2 = BC3 for the next step, from the most conservative value of reactivity insertion. In this case, the BC2 control bar was removed at the percentage of 2/3 of the most conservative bar removal value that provides the lowest percentage bar removal. In the same way it is followed by the removal of BC3 of control rod percentage of the in the same value;

7- After stabilizing the count values of the starting channels obtained from the asymptotic behavior of the same displayed in the data acquisition system (SAD) reactor, the data acquisition (C1,C2 and C9) is starting at an acquisition time 60 seconds;

8- The steps referring to items 4 to 7 continued until the critical prediction of the rods of the 3 starting channels 1,2 and 9, converged to values between themselves within a percentage deviation of 1%; In this situation we arrive at Step 8 given in Table I;

9- Step 9 was not performed with the respective critical positions of control rods, as the analysis of the 1/M values of step 8 already indicated a critical forecast of 65.09%, 65.18% and 65.08%, respectively for the starting channels 1 ,2 and 9. These values are lower than the 1% given in the previous item. With that, the criticalization of the reactor was directly passed, keeping the BC2 control rod at 65.12% (average value of the 3 estimates) removing the BC3 bus above this value to a condition of supercriticality, taking care of the period of neutron population growth to remain below 100 seconds, as provided for in the procedure;

10- Having reached the value electric current given in linear channel 6 of C6= 0.765.10-7 ampere, value estimated to 1 watt, BC3 was successively inserted, stabilizing the power for oscillations that could be controlled by the automatic control of the reactor. After 10 minutes of stabilization on the automatic control acting in the BC3, the critical positions were BC1=BC4=64.23%, BC2= 65.12% and BC3 = 65.20%;

11- Subsequently, the redistribution of equal percentage positioning of the control bars removed from the 4 rods is carried out and after a stabilization time with the automatic control oscillating around BC3 = 64.64% (oscillating), it was obtained for the other control rods fixed at BC1=BC2=BC4 = 64.67%.

3. Results and Discussion

The results obtained from the counts of the starting channels 1,2 and 9 of the reactor IPEN/MB-01 used in the prediction of criticality resulting from the insertion of reactivity due to the removal of control rods BC2 and BC3 are summarized in Table 1. Thus, at 11:11 am on March 3, 2020, the critical positions of the control rods were obtained, the control rods BC1 and BC4 kept fixed at 64.23% (critical positions estimated by neutron calculation for the 4 bars of control equally removed), for BC2 and BC3, respectively, 65.12 % and (65.20 ± 0.03) %. After redistributing the position of the critical positions of bars, the value of 64.67% was obtained for the 4 control bars equally removed with the moderator at a temperature of 20.79 ˚C .

4. Conclusions

This work presents the sequence of steps, after loading the core with 19 plate-type fuel elements (MTR), to obtain the initial criticality of the IPEN/MB-01 reactor. The critical control rods positions were obtained after analyzing the neutron multiplication inverse curve through the counts of the starting channels 1, 2 and 9 as a function of the percentage of removal of the control rods from the active core of the reactor IPEN/MB-01. The value obtained in this paper is only 0.69 % different that calculated by MCNP 5 code to values of control rods equally withdrawn of the core reactor.

Table I - Data obtained during the critical position of Control rods

Step	**BC2=BC3**	C1	C2	C9	(1/M1)	(1/M2)	(1/M9)	Temperature moderator
1	10%	2131	681	1978	0.9129	0.9043	0.8954	19.69±0.03
2	20%	2621	845	3897*	0.7400	0.7289	0.4541*	19.60±0.03
3	30%	3454	1098	3269	0.5632	0.5609	0.5415	19.56±0.04
4	40%	5248	1657	5002	0.3707	0.3719	0.3538	19.57±0.01
5	50%	9740	3117	9572	0.1997	0.1977	0.1849	19.57±0.02
6	57%	21246	7008	20945	0.0916	0.0879	0.0845	20.77±0.02
7	60.74%	41895	13420	42064	0.046	0.046	0.042	20.78±0.02
8	63.21%	96832	30822	97485	0.020	0.020	0.018	20.78±0.02
9	**65.12%**	-	-	-	0	0	0	**20.79±0.06**

Reference Counts: $C_0 1$ = 1945; $C_0 2$=616; $C_0 9$=1770; **BC1=BC4= 64.23%** in all steps.
* Value neglected in step 2 due to interference due to electronic noise.

Acknowledgements

Thanks to all IPEN/CNEN, Amazul and CTMSP colleagues who contributed to the design, installation and criticalization of the new core with plate-type fuel elements in the IPEN/MB-01 reactor.

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