CALCULATION-MEASUREMENT COMPARISON FOR CONTROL RODS REACTIVITY IN RA-3 NUCLEAR REACTOR

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ABSTRACT

The RA-3 Nuclear Reactor of the Atomic Energy National Commission from Argentina, begun working with high enrichment fuel elements in 1967, and turned to low enrichment by 1990.

During 1999 it was found out that several fuel elements had problems, so more than 50 % of them had to be removed from the core. Because of this, it was planned to go from core 93 to core 94 with special care from nuclear safety point of view. Core 94 was preceded by other five, T-1 to T-5, only as transitory ones. The care implied several nuclear parameters measurements: core reactivity excess, calibration of control rods, etc.

Calculations were performed afterwards to simulate those measurements using the neutron diffusion code PUMA. The comparison shows a good agreement for more than 80% of the cases with differences lower than 10% in reactivity. The greatest differences were found in the last part of the control rods calibration and a better calculation of cell constants is planned to be done in order to improve the adjustment.

INTRODUCTION

The RA-3 Nuclear Reactor, in Ezeiza Atomic Center, CNEA, was built in 1967. It is swimming pool type, refrigerated and moderated with light water. The core consists of 25 leu fuel elements (19.7%), 22 graphite reflector boxes, 6 irradiation boxes, one of which is in the middle of the core, and a thermal column. The main uses are: radioisotope production, activation analysis, test of fuel element prototypes, irradiation damage studies, etc.

During 1999 it was found out that several fuel elements had problems, so more than 50 % of them had to be removed from the core. Because of this, it was planned to go from core 93 to core 94 with special care from nuclear safety point of view. Core 94 was preceded by five ones, T1 to T5, only as transitory cores. The care implied several nuclear parameters measurements. Among them the core reactivity excess and calibration of control rods for cores N°93, T1 to T5 and 94 /1/.

It was revised the beta effective value (β_{eff}) because of the disagreement between power measured by neutron noise and by thermohydraulics. /2/. Also, this new value of β_{eff} was applied to pcm and dólar reactivity worth equivalence.

The present work shows the calculation-measurement comparison for core excess reactivity and control rods worth in cores 93, T-1 to T-5 and 94.

Experimental Methodology

The reactivity of the control rods was obtained by the inverse kinetics procedure, by introducing or extracting the control rods in several steps. The procedure PC implementation with ADC card is the

"Digital Reactimeter" /3/. The different measurements in 93 to 94 cores were done with "FERCIN-1" software /4/. The results can be seen in ref. /1/.

The control rod calibration is done beginning with the core in a critical configuration of the control rods (rho equal zero). The selected rod to be calibrated is introduced partially and the reactivity of this part of the rod is measured. Then a compensation rod is extracted until the core criticality condition is obtained. This procedure is repeated until the control rod is 100% introduced.

The ρ_{ex} is deduced from the rod calibration adding the reactivities of the parts of these rods introduced in the core for $\rho = 0$ state.

Calculation Methodology

The calculations were done using the neutron diffusion code PUMA, in tridimensional, two energy-group model of the core. The fuel element model consists of two regions: meat and frame. In addition, an other region is differentiated for the case of control rods, which corresponds to fork of Ag-In-Cd, that controls the reactivity. Each region corresponds to a set of cell constants that are generated with WIMS-D4, the neutron unidimensional transport code.

In the calculation we try to simulate as close as possible the measurement steps. Because in PUMA the axial axis is simulated by 8 parts (12.5 % each) some experimental calibration steps were linearly interpolated.

MEASUREMENTS AND CALCULATIONS

In what follows it is shown some control rod calibrations and other data for each core.

- **CORE 93**

To test the measurement instrumentation we begun with Core 93. This one had 25 fuel elements y 22 graphite reflector boxes. ρ=0 state was reached with the following control rods (CR) configuration:

CR1(F3): 100% CR2(H4): 100% CR(F5): 100% CR4(E4): 15.7%

where position in the core, extracted percentage and core position for each control rod is indicated.

Measured and calculated CR2 calibration (Fig.I), reactivity comparison and core reactivity excess (ρ_{exc}) (Table I) and core configuration (Fig. II) are now shown.

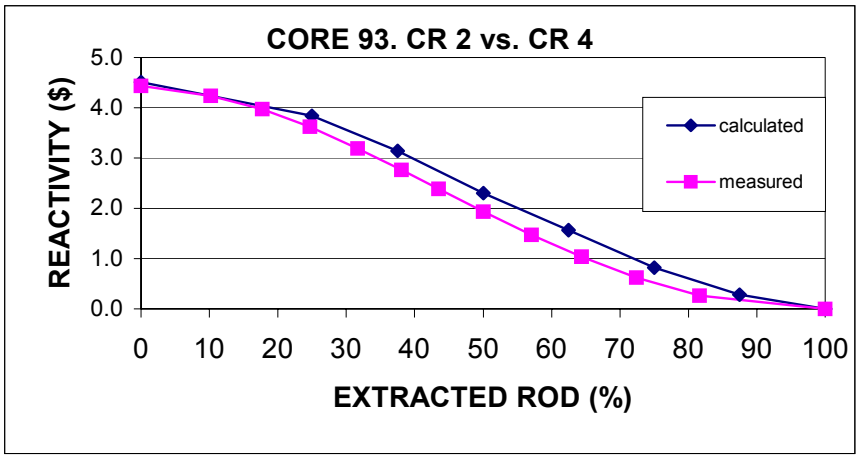

Fig. I: Core 93 Measured and calculated CR2 vs CR4 calibration

TABLE 1. CORE 93.
Measured and calculated reactivities. Comparison.

	CALCULUS	MEASURED	DIFFERENCE
ρ(EXCESS)	5.073 $	5.075 $	-0.04 %
CR2	4.51 $	4.43 $	1.8%
CR4 (15.7%-72.4%)	4.24 $	4.43 $	-4.5%

	C	D	E	F	G	H	I	J
1		Graphite	Graphite	Graphite	Graphite	Graphite	Graphite	
2	Graphite	Irradiat. Box.	**C041 0,71%**	**A152 47,72%**	**C007 50,31%**	**C001 50,44%**	Irradiat. Box..	Graphite
3	Graphite	**P-01 46,54%**	**C030 11,03%**	**CR1 CS011 8,39%**	**C036 0,99%**	**C031 24,83%**	**C009 49,45%**	Graphite
4	Graphite	**CS002 41,46%**	**CR4 CS005I 3,13%**	**C027 3,56%**	Irradiat. Box.	**CR2 CS005 32,15%**	**C025 25,33%**	Graphite
5	Graphite	**A153 48,78%**	**C028 24,31%**	**CR3 CS009 19,53%**	**C032 2,02%**	**C039 16,07%**	**C005 49,51%**	Graphite
6	Graphite	Irradiat. Box.	**C002 51,14%**	**C003 48,10%**	**A095 47,30%**	**C010 50,90%**	Irradiat. Box.	Graphite
7		Graphite	Graphite	Graphite	Graphite	Graphite	Graphite	

Fig. II: Core 93

CORE T-1

Core T-1 had same configuration as 93 without 6 graphites (Fig III).

	C	D	E	F	G	H	I	J
1		Graphite			Graphite		Graphite	
2	Graphite	Irradiat. Box.	**C041 0,71%**	**A152 47,72%**	**C007 50,31%**	**C001 50,44%**	Irradiat. Box..	Graphite
3	Graphite	**P-01 46,54%**	**C030 11,03%**	**CR1 CS011 8,39%**	**C036 0,99%**	**C031 24,83%**	**C009 49,45%**	Graphite
4	Graphite	**CS002 41,46%**	**CR4 CS005I 3,13%**	**C027 3,56%**	Irradiat. Box.	**CR2 CS005 32,15%**	**C025 25,33%**	Graphite
5	Graphite	**A153 48,78%**	**C028 24,31%**	**CR3 CS009 19,53%**	**C032 2,02%**	**C039 16,07%**	**C005 49,51%**	Graphite
6	Graphite	Irradiat. Box.	**C002 51,14%**	**C003 48,10%**	**A095 47,30%**	**C010 50,90%**	Irradiat. Box.	Graphite
7		Graphite			Graphite		Graphite	

Fig. III: Core T-1

Critical configuration for this core implied the following CR position:

CR1: 100% CR2: 100% CR3: 100% CR4: 41.6%

As resulted from measurements and calculation we had the following CR4 calibration and C-M comparison.

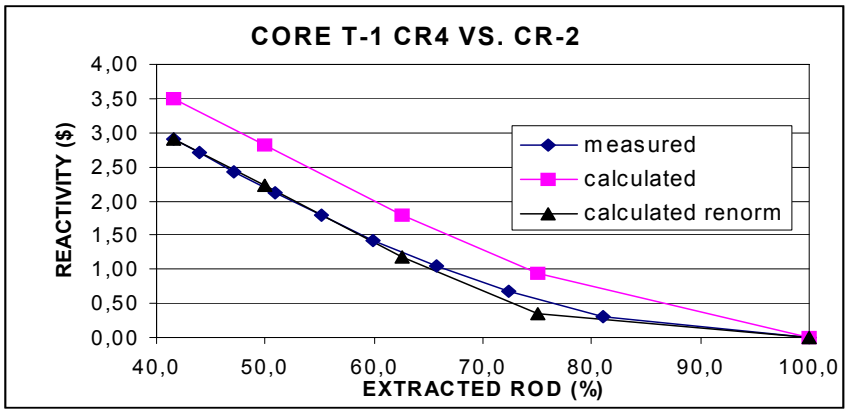

Fig. IV: Core T-1. Measured and calculated CR4 vs CR2 calibration

TABLE 2. CORE T-1. Measured and calculated reactivities. Comparison.			
	CALCULUS	MEASURED	DIFF (%)
□ (EXCESS)	3.39	2.97 $	12.4 %

Core T-2

For Core T-2 C030 fuel element in E3 position was retired and the six graphites incorporated into the core again (that is, core 93 without C030).

ρ=0 state for this core implied the following CR positions:

CR: 100% CR2: 100% CR3: 100% CR4: 69%

$\rho_{(exc)}$ measured was 0.69 $. By calculations it was estimated as 0.81$. CR4 calibration wasn't done by calculus.

	C	D	E	F	G	H	I	J
1		Graphite	Graphite	Graphite	Graphite	Graphite	Graphite	
2	Graphite	Irradiat. Box.	**C041 0,71%**	**A152 47,72%**	**C007 50,31%**	**C001 50,44%**	Irradiat. Box..	Graphite
3	Graphite	**P-01 46,54%**		**CR1 CS011 8,39%**	**C036 0,99%**	**C031 24,83%**	**C009 49,45%**	Graphite
4	Graphite	**CS002 41,46%**	**CR4 CS005I 3,13%**	**C027 3,56%**	Irradiat. Box.	**CR2 CS005 32,15%**	**C025 25,33%**	Graphite
5	Graphite	**A153 48,78%**	**C028 24,31%**	**CR3 CS009 19,53%**	**C032 2,02%**	**C039 16,07%**	**C005 49,51%**	Graphite
6	Graphite	Irradiat. Box.	**C002 51,14%**	**C003 48,10%**	**A095 47,30%**	**C010 50,90%**	Irradiat. Box.	Graphite
7		Graphite	Graphite	Graphite	Graphite	Graphite	Graphite	

Fig. V: Core T-2

- **Core T-3**

C030 fuel element was introduced again and some fuel elements were changed. Criticality was reached with the following CR positions:

BC1: 94.2% BC2: 100% BC3: 100% BC4: 0%

	C	D	E	F	G	H	I	J
1		Graphite	Graphite	Graphite	Graphite	Graphite	Graphite	
2	Graphite	Irradiat. Box	**C041 0,71%**	**A152 47,72%**	**A093 45,50%**	**C001 50,44%**	Irradiat. Box.	Graphite
3	Graphite	**P-01 46,54%**	**C030 11,03%**	**CR1 CS011 8,39%**	**C036 0,99%**	**C031 24,83%**	**CS008 0,00%**	Graphite
4	Graphite	**CS002 41,46%**	**CR4 CS005I 3,13%**	**C027 3,56%**	Irradiat. Box	**CR2 CS005 32,15%**	**C025 25,33%**	Graphite
5	Graphite	**A153 48,78%**	**C028 24,31%**	**CR3 CS009 19,53%**	**C032 2,02%**	**C039 16,07%**	**C005 49,51%**	Graphite
6	Graphite	Irradiat. Box	**C002 51,14%**	**A088 47,96%**	**A095 47,30%**	**C010 50,90%**	Irradiat. Box	Graphite
7		Graphite	Graphite	Graphite	Graphite	Graphite	Graphite	

Fig. VI: Core T-3

Fig.VIII: Core T-3. Measured and calculated CR2 vs CR4 calibration

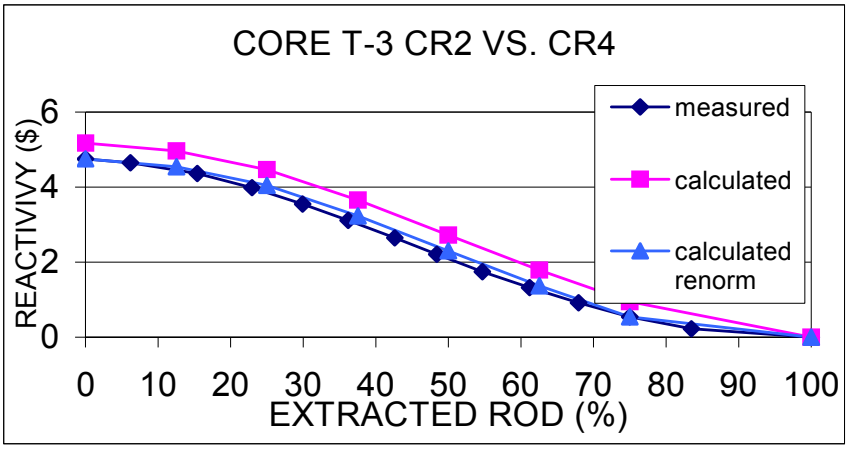

TABLE 3. CORE T-3. Measured and calculated reactivities. Comparison.			
	CALCULUS	MEASURED	(C-M)/C
□ (CR2)	5.17 $	4.75 $	8.1 %

Core T-4

For Core T-4 several fuel elements were rotated and one with 50% burnt-out was changed by a fresh one. Criticality was reached with the CR positions:

BC1: 100% BC2: 100% BC3: 100% BC4: 20.6%

	C	D	E	F	G	H	I	J
1		Graphite	Graphite	Graphite	Graphite	Graphite	Graphite	
2	Graphite	Irradiat. Box	**C041 0,71%**	**A152 47,72%**	**A093 45,50%**	**C036 0,99%**	Irradiat. Box.	Graphite
3	Graphite	**P-01 46,54%**	**C039 16,07%**	**CR1 CS011 8,39%**	**C031 24,83%**	**C027 3,56%**	**CS008 0,00%**	Graphite
4	Graphite	**CS007 0,00%**	**CR4 CS005I 3,13%**	**C028 24,31%**	Irradiat. Box	**CR2 CS005 32,15%**	**A153 48,78%**	Graphite
5	Graphite	**CS002 41,46%**	**C030 11,03%**	**CR3 CS009 19,53%**	**C025 25,33%**	**C032 2,02%**	**C005 49,51%**	Graphite
6	Graphite	Irradiat. Box	**C002 51,14%**	**A088 47,96%**	**A095 47,30%**	**C010 50,90%**	Irradiat. Box	Graphite
7		Graphite	Graphite	Graphite	Graphite	Graphite	Graphite	

Fig. VIII: Core T-4

Fig.IX: Core T-4. Measured And Calculated CR4 Vs CR2 Calibration

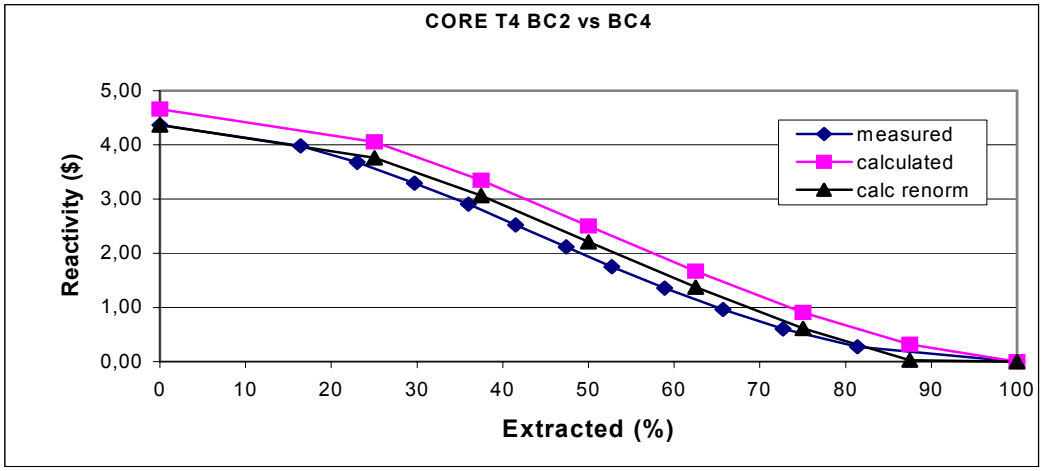

Fig.X: Core T-4. Measured and calculated CR2 vs CR4 calibration

TABLE 4. CORE T-4. Measured and calculated reactivities. Comparison			
	CALCULUS	MEASURED	(C-M)/C
CR2	4.23 $	4.66 $	-6.6%
CR4 (78,9%-20,6%%)	4.25 $	4.37 $	-2.7%

- **Core T-5**

Two fresh elements were introduced in this Core. Criticality was reached with the following rod positions:

BC1: 60.4% BC2: 100% BC3: 100% BC4: 0%

	C	D	E	F	G	H	I	J
1		Graphite	Graphite	Graphite	Graphite	Graphite	Graphite	
2	Graphite	Irradiat. Box	C034 0,00%	A152 47,72%	A093 45,50%	C036 0,99%	Irradiat. Box.	Graphite
3	Graphite	P-01 46,54%	C039 16,07%	CR1 CS011 8,39%	C031 24,83%	C027 3,56%	CS008 0,00%	Graphite
4	Graphite	CS007 0,00%	CR4 CS005I 3,13%	C028 24,31%	Irradiat. Box	CR2 CS005 32,15%	A153 48,78%	Graphite
5	Graphite	CS002 41,46%	C030 11,03%	CR3 CS009 19,53%	C025 25,33%	C032 2,02%	C033 0,00%	Graphite
6	Graphite	Irradiat. Box	C002 51,14%	A088 47,96%	A095 47,30%	C041 0,71%	Irradiat. Box	Graphite
7		Graphite	Graphite	Graphite	Graphite	Graphite	Graphite	

Fig. X: Core T- 5

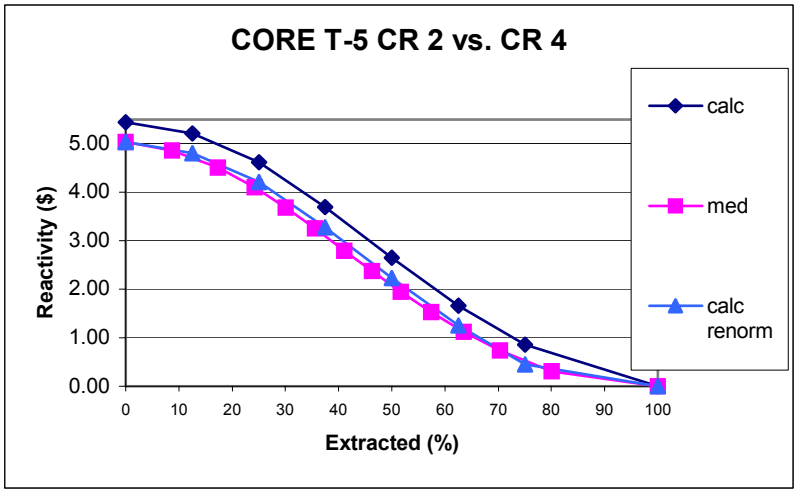

Fig.XI: Core T-5. Measured and calculated CR2 vs CR4 calibration

TABLE 5. CORE T-5. Measured and calculated reactivities. Comparison.			
	CALCULUS	MEASURED	DIFFERENCE
ρ (EXCESS)	6.77$	6.25 $	8.3 %
CR2	5.45 $	5.04 $	7.5%
CR4 (78.9%-20.6%)	5.32 $	4.91 $	7.7%

- CORE 94

Finally, we arrived at Core 94 changing another burned element by a fresh one. The criticality configuration of control rods was

BC1: 48.6% BC2: 100% BC3: 100% BC4: 0%

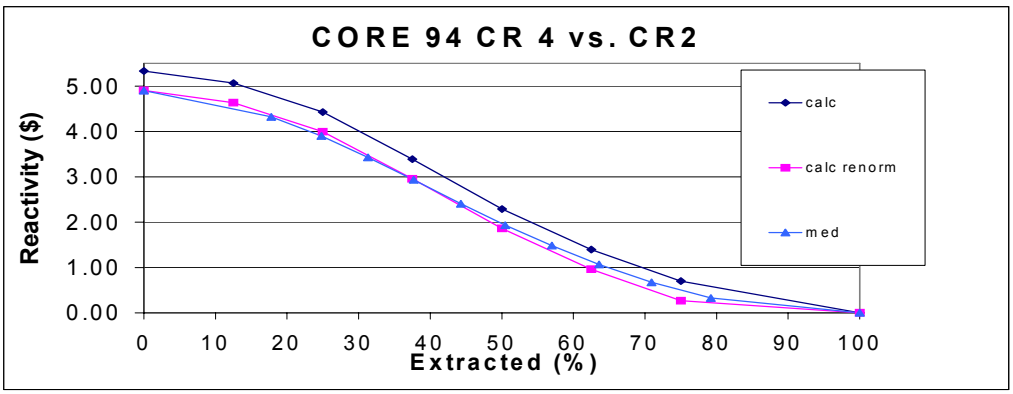

Fig.XI: Core 94. Measured And Calculated Cr4 Vs Cr2 Calibration

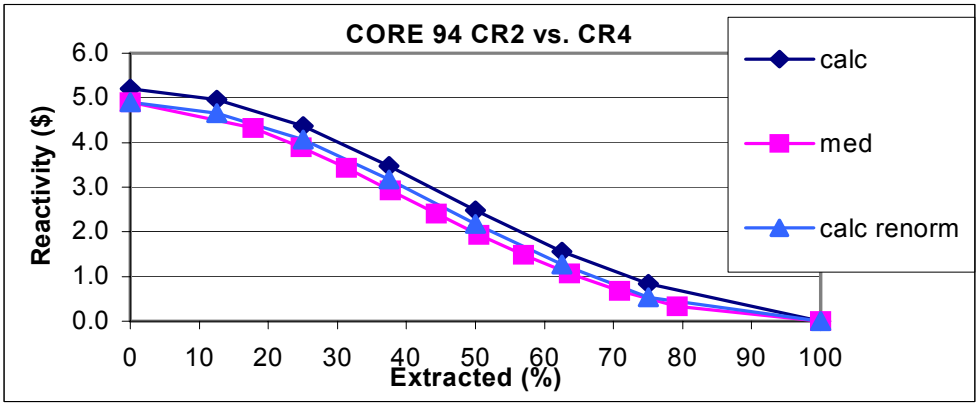

Fig.XII: Core 94. Measured And Calculated CR2 Vs CR4 Calibration

TABLE 6. CORE 94.
Measured and calculated reactivities. Comparison.

	CALCULUS	MEASURED	DIFFERENCE
ρ (EXCESS)	7.55 $	6.99 $	7.4 %
CR2	5.20 $	4.90 $	6.8%
CR4	5.33 $	4.97 $	7.7%
CR1	4.77 $	5.07 $	-6.3%

	C	D	E	F	G	H	I	J
1		Graphite	Graphite	Graphite	Graphite	Graphite	Graphite	
2	Graphite	Irradiat. Box	C034 0,00%	A152 47,72%	A093 45,50%	C036 0,99%	Irradiat. Box.	Graphite
3	Graphite	P-01 46,54%	C039 16,07%	CS011 8,39%	C031 24,83%	C027 3,56%	CS008 0,00%	Graphite
4	Graphite	CS007 0,00%	CS005I 3,13%	C028 24,31%	Irradiat. Box	CS005 32,15%	A153 48,78%	Graphite
5	Graphite	CS002 41,46%	C030 11,03%	CS009 19,53%	C025 25,33%	C032 2,02%	C033 0,00%	Graphite
6	Graphite	Irradiat. Box	C037 0,00%	A088 47,96%	A095 47,30%	C041 0,71%	Irradiat. Box	Graphite
7		Graphite	Graphite	Graphite	Graphite	Graphite	Graphite	

Fig. XIII: Core 94

- **Analysis.**

We summarize the results in the following table.

TABLE 7
Measured and calculated reactivities. Comparison

CORE	CONTROL ROD		ρ_{CALC} ($)	ρ_{MEASUR} ($)	Dif. (%)
93	ρ (CR 2)	100.0%-00.0%	4,51	4,43	1,8%
93	ρ (CR 4)	15,7%-72,4%	4.24	4.23	-4,5%
93	ρ	CORE	5,07	5,07	0,0%
T-1	ρ (CR 2)	100%-30,4%	3,39	2,97	12,4%
T-1	ρ (CR 4)	41,6%-100.0%	3,51	2,91	17,0%
T-3	ρ (CR 2)	100.0%-00.0%	5,17	4,75	8,1%
T-4	ρ (CR 2)	100.0%-00.0%	4,37	4,66	-6,6%
T-4	ρ (CR 4)	78,9%-20,6%	4,25	4,37	-2,7%
T-5	ρ (CR 2)	100.0%-00.0%	5,45	5,04	7,5%
T-5	ρ (CR 4)	100.0%-00.0%	5,32	4,91	7,7%
T-5	ρ (CR 1)	60,4%-100.0%	1,44	1,21	16,2%
T-5	ρ (CR 3)	100.0%-57,1%	1,49	1,34	9,9%
T-5	ρ	CORE	6,77	6,12	9,5%
94	ρ (CR 2)	100.0%-00.0%	5,20	4,90	5,8%
94	ρ (CR 4)	100.0%-00.0%	5,33	4,97	6,8%
94	ρ (CR 3)	100.0%-47,6%	2,22	2,02	8,7%
94	ρ	CORE	7,55	6,99	7,4%
94	ρ (CR 1)	100.0%-00.0%	4,77	5,07	-6,3%

By inspection of the summary (Table 7) it can be observed that in15 cases measured and calculated reactivity worth agreed within 10%.

Also, we saw that in several cases were the C/M >1. In such cases we renormalized the calculated values, subtracting the difference of the calculated and measured integral reactivity rod worth. This procedure implied a better adjust in calibration curves. (For example, Fig. X, XI, XII).

Two hypotheses were thought. One is concerned with the fact that the fork of the control rod is longer than meat (63.5 vs 61.5) and this implied an uncertainty in what means 100% extracted for the rod. The other was about the matrix that simulates the core above the 61.5 cm of meat, that is not explicit in PUMA.

Conclusions.

A good agreement was reached in the calculated and measured comparison of control rod worth and reactivity excess for different cores. The most part of the cases falls in the 10% range of difference.

It remains the necessity to find a good answer to the positive differences in several cases. We expect that new cell constants calculation for an improvement of the reactor model, a task to be done during the next year, will give the correctness of the given hypothesis.

References.

/1/ Gómez A., Estryk G., Roqueta D. “Mediciones de parámetros neutrónicos del reactor RA-3 durante la puesta en marcha en mayo del año 2000”. CNEA.C.RCN.ITE.136 (2000).

/2/ Estryk G. “Cálculo de la fracción efectiva de neutrones retardados en combustible de bajo enriquecimiento. Caso del reactor RA-3 de la CNEA”. IN14EF02. Rev .0 (2002).

/3/: Waldman R. Gomez A., "Utilización de un sistema de adquisición de datos para medir la efectividad de barras de control, empleando el modelo de la cinética puntual ("reactímetro digital")"CNEA-GI-I.T. 1197/88.

/4/: Gomez A., "Sistema de medición y software utilizados en cinética inversa y ruido neutrónico en reactores de investigación", CNEA.C.RCN.ITE.025. 1997 (Rev.1).