COMPARISON BETWEEN EXPERIMENTAL RESULTS AND CALCULATIONS DURING THE COMMISSIONING OF THE ETRR2

Eduardo Villarino[1], Carlos Lecot[1], Ashraf Enany[2] and Gustavo Gennuso[3].

This work presents the comparison between calculated and experimental values of several cores assembled during the low power test of the Commissioning of the ETRR2. These values include the calculation of critical cores, shutdown margins, reactivity excesses, control rod worths, and Second Shutdown System worth. Basically, five different core configurations were analyzed in depth, namely water reflected, with Beryllium reflectors (1 and 2 faces reflected) and with and without the in-core cobalt irradiation device. One important feature of the core configuration is that there are three different types of fuel elements. This paper briefly describes the core characteristics of the ETRR2 reactor, the calculation codes and models, a detailed information of several measurements carried out during the commissioning and the comparison between calculation and measurements.

ETRR2 DESCRIPTION

The ETRR-2 core is an array of fuel elements, reflectors, absorber rods, gadolinium injection boxes and irradiation devices. Fuel elements can be placed in different arrangements. The basic geometric unit in the X-Y core array is a square of 8.1x8.1 cm^2. It can house an 8.0x8.0 cm^2 fuel element, an empty box or an irradiation device.
As it is shown in figure 1, inside the chimney there is a 30 positions grid with a 6x5 configuration. It is divided by two 2 structural guide plates (for control rods insertion). ETRR2 reactor uses six flat plates as absorber rods which can be inserted into the core with a high velocity. Guide-plate channels are made up of aluminum. There are 2 guides on the grid with 3 absorber plates inside each one, arranged in two parallel groups.
Around the chimney there is an external grid array. The irradiation grid has locations where reflectors, empty boxes and irradiation devices can be placed. Graphite thermal column and beryllium block are both divided into a set of independent reflectors and a solid block.

CALCULATION CODES

The calculation method is divided in two steps:

a) Cell calculation: It is used to calculate macroscopic cross sections of different materials for the core calculation.
b) Core calculation: It is used to calculate neutronic parameters of the core as neutron fluxes, power and Burnup distribution, reactivities, peaking factor, cycle length, kinetic parameters, etc.

All the codes used belong to the MTR_PC system and they are:

1) The nuclear data library used for calculation was the original WIMS library with updates from ENDF/B-IV of Ag, In, Cd, and Gd. /1/
2) WIMS /2/. The collision probabilities option in one dimensional geometry (slab) is used for cell calculation.
3) POS_WIMS /3/. This program is used to homogenize and condense macroscopic XS from WIMS calculation.
4) CITVAP 3.1 /4/. It is a core diffusion code. It is a new version of CITATION II program.
5) HXS 4.1 /5/. It is the macroscopic cross section library manager program. It is used for the interface between cell and core calculation.

Presenting Author Eduardo Villarino
[1] *INVAP SE. F. P. Moreno 1089. San Carlos de Bariloche. Rio Negro. Argentina.*
[2] *INSHAS, Atomic Energy Authority, ETRR-2, 13759, Cairo, Egypt.*
[3] *C.A.B. E. Bustillo Km 9. San Carlos de Bariloche. Rio Negro. Argentina*

CALCULATION MODELS

For the evaluation of the cell constants the WIMS code is used in slab geometry. The results of WIMS calculations are processed in different ways to obtain the core constants for the different materials.

The core calculation is performed with the CITVAP diffusion code in x-y-z with an energy discretization of three groups :

Group 1 : 10.000 Mev -> 0.821 Mev
Group 2 : 0.821 Mev -> 0.625 ev
Group 3 : 0.625 ev -> 0.000 ev

A conceptual description of the most important core components is given in the following subsections.

Standard Fuel Element

The macroscopic XS of the whole standard fuel element is homogenized after a WIMS calculation.

Control Element Zone

The control rod zone is divided in different zones at core level calculation:

1. A zone of Aluminum and water outside the active width of the absorber, corresponding to the ends of the guide box.
2. If the absorber rod is in, there is a homogenized zone of Aluminum, water, stainless steel, Helium and Ag-In-Cd. It was verified by core calculations that a homogenization of all the zones inside and including the guide plates is good enough for control rod worth calculation.
3. If the absorber plate is out, the space it leaves in the guide box is occupied by the follower rod (coupling rod). The model has two homogeneous regions:
    a. The zone outside of the follower: Aluminum and water.
    b. The follower zone: Aluminum, water and stainless steel.

Gadolinium Injection Zone

The gadolinium injection zone is divided in different zones at core level calculation:

a) The corner of the chimney: which is made of pure Zircalloy. Some Zircalloy is not considered in the calculation.
b) The horizontal faces (see figure 1) of the chimney have different water gaps than the vertical ones. This is approximated by averaging the water gaps.

EXPERIMENTAL PROCEDURES

Critical Approach

Critical approaches were made by fuel loading and control rod extraction. Fission chambers of the start channel nuclear instrumentation were used for record the count data at each step. The normalized inverse count was plotted against the F(x) function which takes into account the reactivity shape of the control rod, in order to obtain an approximate linear curve in the case of the control rod approach
For fuel mass approach a core configuration with all control rods out was defined as the searched configuration. When the curve prediction indicated that the next configuration could be critical, detailed control rod approach was made. Critical configurations were defined without neutron source.

For reactivity excess, control rod calibrations were made by the usual period method, and Keepin constants were used for reactivity determination. In order to reduce the measurement time when one control rod was calibrated the rest of the control rods were calibrated by compensation against one calibrated control rod. The selection of the control rod for compensation depends on the relative position to the other moving rod, in order to minimize the shielding effect.
It was decided to use the nuclear instrumentation of the reactor for all the measurements. For reactivity calibration the signal of the three fission chambers of the start channel was connected to an ADC and PC system. It was possible to take data (counts) in adjustable periods of 50 msec. The recorded data were processed by the Rodcal program, giving us the reactivity value in each step by

adjusting the period to the curve counts vs. time. Waiting time to begin the adjustment was determined experimentally for periods of about 30 sec. A special procedure was made when the core was surrounded by Beryllium. In this case the contribution of the photoneutron source of the beryllium reflector was estimated as new groups of delay neutrons using experimental and bibliographic data. The conclusion is that in this case the effect can be neglected but special care has to be taken for the critical position at each step to avoid confusing subcritical states with critical states by the photoneutron source Beryllium effect. In this procedure the critical state at each step was reached at such power that the source effect was neglected but low enough to be sure that the feedback temperature effect does not disturb. In this critical position the control rod position was recorded and then the power was decreased to a low value so it was possible to run the reactor for the period method. In the lower power level the recorded control rod critical position was repeated.

Shutdown margins

For shutdown margin the Integral Rod Drop method was applied using the same record data system as described above. The recorded data were processed by Origin 4.01 software and the spatial effects were corrected, as a first approximation, by calculus estimation in the detector position. The error corresponds to the error propagation of the Integral formula for the values corresponding to each fission chamber and then a mean value and its error were obtained

Second shutdown system reactivity

For critical reactor it was possible to fill three Gd chambers. The reactivity worth for the three chambers was obtained comparing the reactivity excess with and without Gd

MEASUREMENTS

Nine different core configurations were assembled during the low power test of the commissioning, the core configurations measured were (see Figure 1 as reference figure):

- Core SU-27. It is a core configuration without Beryllium reflectors and Irradiation boxes on Irradiation grid The core grid is filled with FE as it is shown in Figure 1 but without the FE F1 and F5. It was the first critical core with the neutron source device inside the core irradiation box (D3).
- Core SU-28. It is a core configuration similar to the core SU-27, but with a FE in position F5. It was the first critical core without the neutron source device.
- Core SU-29. It was the first measured core configuration without Beryllium reflectors.
- The Beryllium reflectors were added sequentially from core SU-29, starting with the core SU-29-1Be (only one core face with Beryllium reflectors irradiation grid row C),
- Core SU-29-2Be (two core faces with Beryllium reflectors irradiation grid row C and K),
- Core SU-29-2S0 differs from the 1/98 in one Beryllium reflector in position C-10 and the irradiation boxes,
- Core SU-29-2S1, it is the same as SU-29-2S0, but with two Second Shutdown System chambers filled with water only (Chambers 3 and 4)
- Core 1/98 (See figure 1)
- Core 2/98 is the same configuration as in Core 1/98 but with the Cobalt Irradiation Device inside the in-core Cobalt irradiation position (position D3).

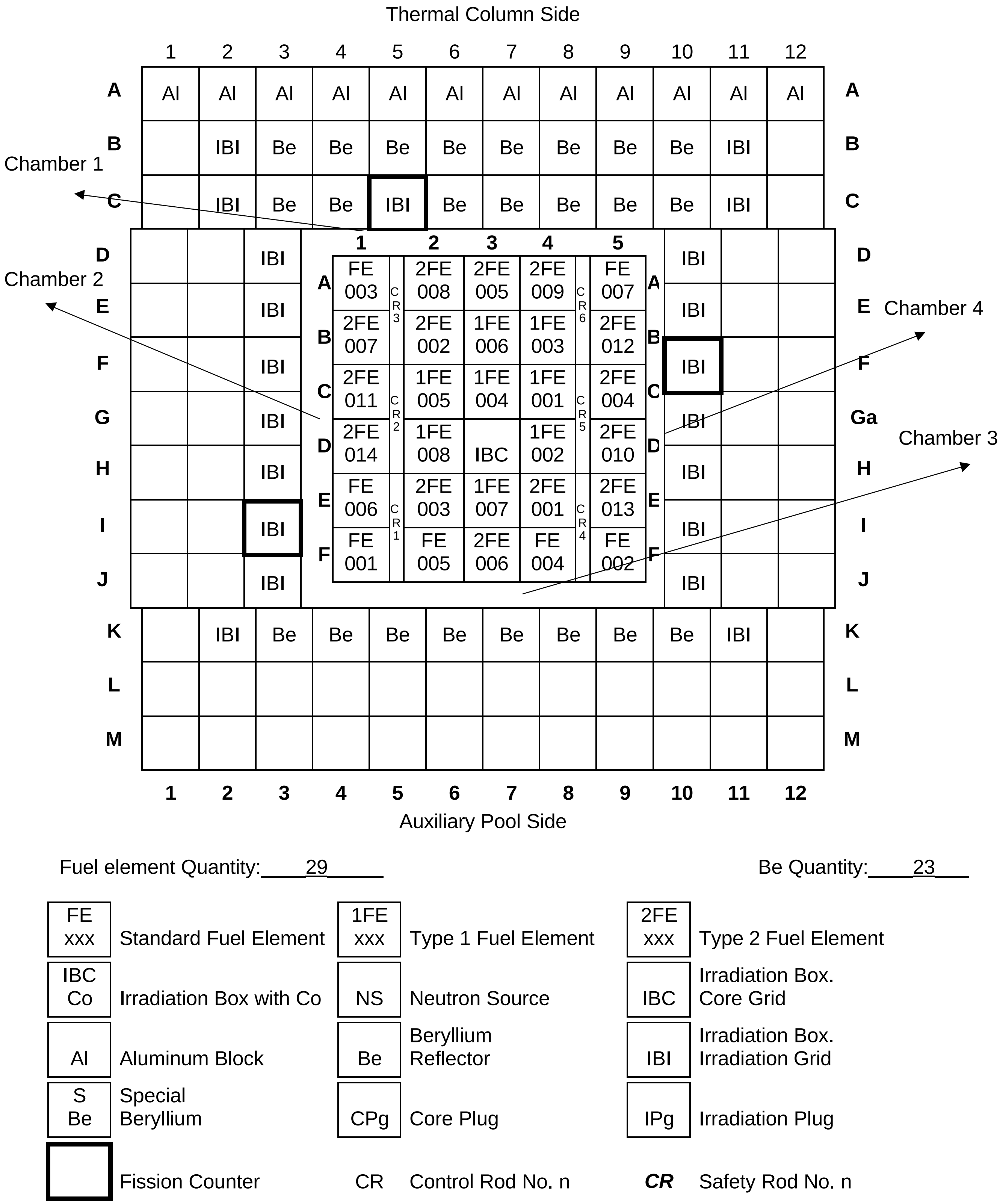

Figure 1: Core configuration for the Core 1/98

MEASUREMENTS AND CALCULATION OF CRITICAL STATES

In the following table there is a detail of the different critical cores reached mainly during control rod calibrations for the mentioned configurations.

Table 1: Critical Cores			
Configuration	Cases	Average reactivity (pcm)	St. Dev. (pcm)
SU-27	1	387	-
SU-28	1	250	-
SU-29	18	192	39
SU-29-1Be	22	270	39
SU-29-2Be	1	317	-
SU-29-2S0	34	479	59
SU-29-2S1	1	336	-
1/98	28	288	44
2/98	31	287	42
All	137	317	104
All except SU-29-2S0	103	267	57

From the analysis of these values can be determined the very good agreement between experimental values (control rod positions in critical cores) and the associated calculated values. Some remarks have to be made regarding the values of the Core SU-29-2S0, the average value of the critical states is much higher than the obtained for the other cores. As the standard deviation is very small, it could mean some systematic error. The differences seems not to be reasonable if they are compared with core 1/98 keeping in mind that these cores are very similar.

SECOND SHUTDWON SYSTEM - CORE 1/98.

The excess reactivity of the core 1/98 allows the filling of only three chambers of the Second Shutdown System (SSS). With the fourth chamber the core would become subcritical. The reactivity worth of the SSS was measured statically (it means by compensating reactivity with a previous calibrated rod) triggering manually one chamber at a time (namely chambers 1, 2 and 4).
Table 2 shows the critical rod positions during the successive filling of the chambers and the calculated values of critical reactivities.
The critical states reached during the calibration of CR-1 when chambers 1, 2 and 4 were filled with the Gd solution give an average value of -425 pcm with a standard deviation of 53 pcm. As it can be seen the average calculated reactivity is very much lower than the values calculated in all other cores, with a very low standard deviation. This means that the high differences are due to the Gd solution that introduces a systematic error in the calculations.

Table2 : SSS Critical Cores	
Chamber with Gd	Critical Core (pcm)
No Gd	310
1	-16
2	160
1 and 2	20
1, 2 and 4	-360

MEASUREMENT AND CALCULATION OF CONTROL ROD WORTHS

For every core configuration some control rods were calibrated to know the excess reactivity of the core. Not all rods were calibrated but some of them were compensated against a previously calibrated control rod. In any case, the effective delayed neutron fraction used to compare measured and calculated data was taken as β_{eff}=750 pcm.

Table 3: Control Rod Worth. Calibrations and compensations					
Core	CR A [range]	CR B [range]	Control rod Worth		
			Measured	Calculated Value	Dif%
SU-29	1 [100 – 24.1]	5 [41.5 - 100]	2.14	2.61	22
SU-29	6 [60.0 – 28.0]	5 [50.5 - 73.7]	0.96	0.86	-10
SU-29-2S0	3 [79.1 - 0] & 6 [100 45.0]	5 [0 - 100]	3.97	3.97	0
SU-29-2S0	5 [62.2 – 55.5]	3 [79.1 - 100]	0.65	0.32	-50
SU-29-2S0	5 [100 – 0.0] & 3 [35.0 - 0.0]	1 [0 - 100]	5.57	4.54	-18
1/98	4 [100 – 0.0] & 2 [53.5 – 52.4]	1 [0 - 100]	3.63	3.78	4.1
1/98	4 [100 – 54.0]	2 [52.8 - 100]	1.63	1.65	1.2
1/98	4 [100 - 0] & 2[52.8 – 49.7]	6 [0 - 100]	3.79	3.32	-12
1/98 + SSS	4 [100.0- 59.7]	1 [65.0 - 100]	1.13	1.17	3.5
2/98	4 [100 - 0] & 2 [100 – 76.8]	1 [0 - 100]	3.85	3.91	1.6
2/98	4 [100 – 24.1]	6 [20.1 - 100.0]	3.61	2.80	-22

Gray rows are control rod compensation

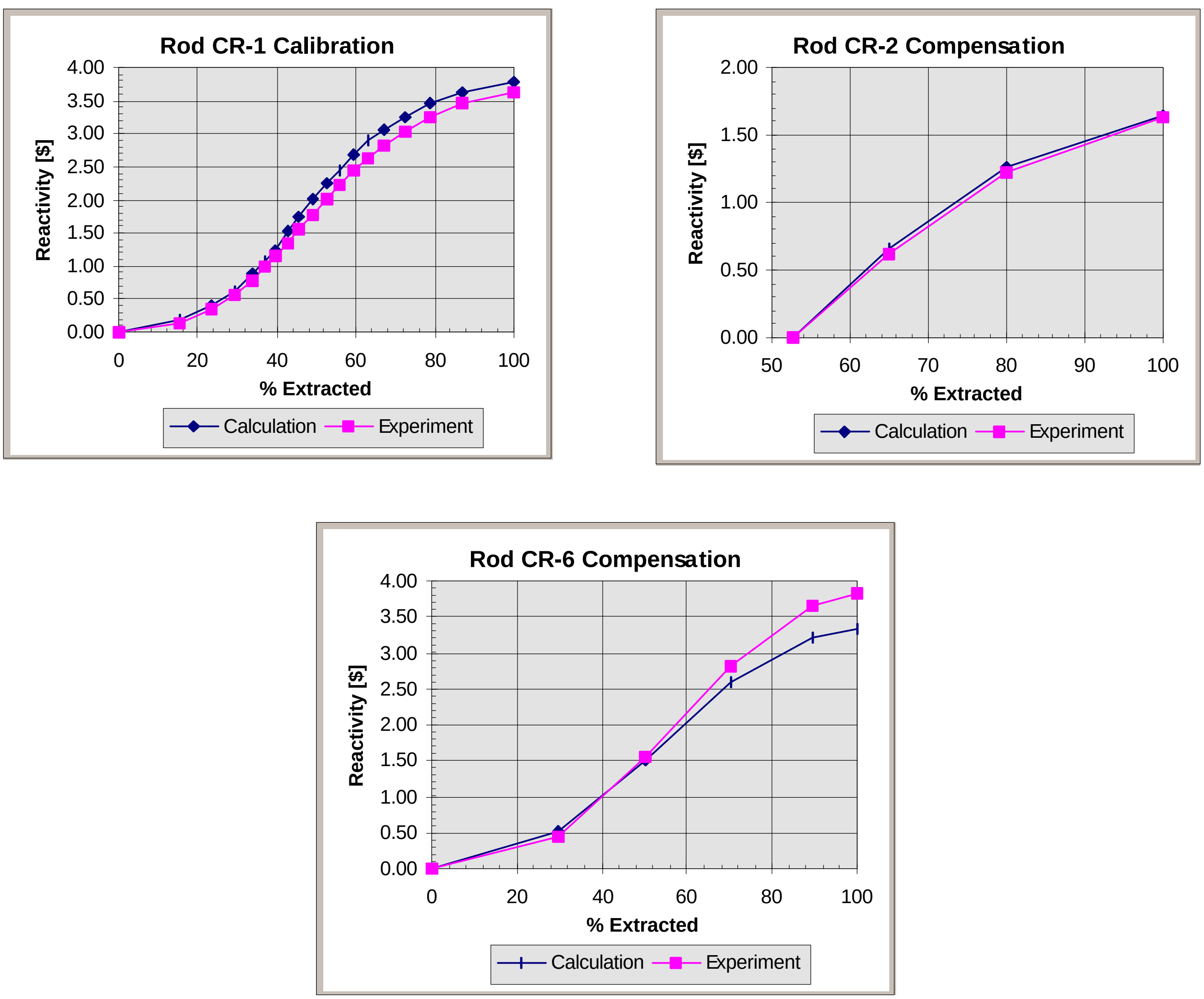

Figure 2: Calibration of CR’s 1, 2 and 6 for Core 1/98.

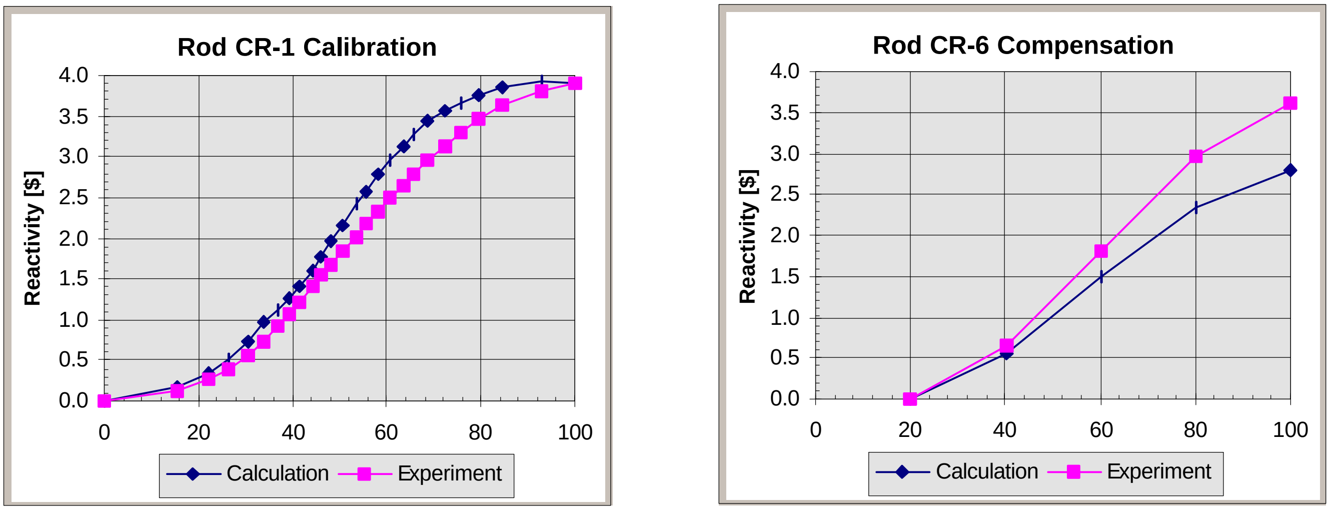

Figure 3: Calibration of CR's 1 and 6 for Core 2/98.

RELEVANT PARAMETERS OF THE CORE CONFIGURATIONS

Table 4: More relevant parameters					
Core	Excess of Reactivity ($)			Shut Down Margin ($) All rods and (Single failure)	
	Measured	Calculation (by calibration)	Calculation (all CR out)	Calculated	Measured
SU-29	2.14	2.61	2.73	19.3	19.9
SU-29-2S0	10.19	8.83	7.75	13.15	12.8
1/98	9.1	8.8	7.9	12.8 (7.1)	15.2 (8.7)
1/98 + SSS	1.13	1.17	0.73		
2/98	7.51	6.7	6.2	15.3 (9.3)	18.4 (12.1)
	Reactivity Worth ($)				
SSS Ch 1	1.95[#]	-	2.39		
SSS Ch 2	2.03[#]	-	2.41		
SSS Ch 1 & 2	5.48[#]	-	4.71		
SSS Ch 1, 2 &4	8.13[#]	7.63	7.17		
SSS Ch 1, 2 &4	7.97[*]	7.63	7.17		
CID* Worth	1.59	2.1	1.7		

Estimated from the control rod calibration of core 1/98
* Difference between measured excess of reactivities
CID: Cobalt Irradiation Device.

CONCLUSIONS

As it was expected due to the good agreement between experiment and calculation (C/E) in the prediction of critical positions, the evaluation of excess reactivities with the calibration or compensation method resulted in a good agreement C/E also. But the conclusion is not so straightforward. It is necessary to point out some comments.

a) Calibrations: calculations and experimental values can only be compared directly in calibrations because in compensations the experimental values are masked by control rod shadowing effects. In calibrations the differences between C/E are not greater than 7% and not greater than 4% in average for all Beryllium reflected cores, even in the Core 1/98 with the SSS where the average critical states are lower than expected. On the other hand, in core SU-29, the only one full water reflected core, the differences are much greater and lie in the order of 22%.

b) In compensation measurements the C/E differences are greater for those rods with more than 50% extracted. The differences, by the other way, decrease when the control rod is almost fully inserted. In other words the C/E difference in reactivity worth of a rod is higher if the compensation has to be made for a short insertion range.

c) In cores with small reactivity excess (it means almost all rod extracted) there is a high agreement between two calculation values (the reactivity excess calculated with all CR's out, and the reactivity excess calculated following the control rod calibration) and the measured value.

d) By the other side, in cores with high reactivity excess, what implies several control rods inserted in the cores, the differences in the values mentioned in the previous paragraph are higher because of the fact that it was necessary to compensate more than one rod. But even in these cases both calculated reactivity excess values predict a good agreement.

e) As a conclusion of the previous paragraphs it can be said that the calculated reactivity excess with all CR's out is in general agreement with the measured values and they can be used to evaluate burnup, cycle lengths, etc, and that the exception could arises when the SSS is triggered, mainly due to an overestimation of the Gd solution reactivity worth.

REFERENCES

1. DIN/GN/001-96 New isotopes in the WIMS library.
2. A general description of the lattice code WIMS, Askew, Fayers & Kemshell, UKAEA, 1967.
3. POS_WIMS. MTR_PC User manual. Julio 1993.
4. CITVAP 3.1. MTR_PC 2.6 User Manual. Julio 1995.
5. HXS 4.0 MTR_PC 2.6 User manual. Julio 1995.

ACKNOWLEGMENTS

The successfully commissioning of the ETRR2 was achieved thanks to the effort of several groups and persons. It is not possible to mention all of them, but the participating groups and institutions involved were: The experimental group of the Centro Atómico Bariloche, Comisión Nacional de Energía Atómica. The operating group of the RA-6 Centro Atómico Bariloche, Comisión Nacional de Energía Atómica. The Egyptian staff of the ETRR2, Atomic Energy Authority of Egypt, and the all INVAP SE personnel working in the ETRR2 project.