DETERMINATION OF THE CONTROL ROD WORTH FOR RESEARCH REACTORS

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INTRODUCTION

Nowadays there is a big interest in developing neutronic analysis methods for research reactor and particularly for the determination of the control rods worth under different operation conditions and core configurations.

The reactivity associated with the control rods is of interest in the shutdown margin and in calculations of possible abnormal conditions related to reactivity accidents.

For theses studies several computer codes have been developed by other authors such as:

— NJOY/AMPX II – HAMMER-TECHNION- CITATION [1]
— NJOY/AMPX II – XSDRNPM – CITATION [1]
— BIPR 5AK [2]
— CASMO-HEX/UKNDL – HEXBU 3D [3]
— ANISN and HEXBU 3D [4]
— Monte Carlo code MCU and the nodal code BIPR 7 [4]
— MAGDA 3CH – MOBY DICK [5]
— PYTHIA-Q [6]
— TWOTRAN-II discrete ordinates and KENO-IV Monte Carlo codes [7].

Our working group has done some work in the neutronic and the safety analysis of Research Reactors.

The present work is aimed at the validation of the calculation methods of the Nuclear Technology Center of Cuba. For this purpose, in order to evaluate the safety of this type of installations, the reactivity worth of the control rods of the cylindrical configuration of the Brazilian critical assembly IPEN/MB-01 is determined. These calculations, however, are a relatively complex task that requires the use of three-dimensional models. Because of this, the validation of the calculation methods used for this purpose is of great importance.

In fact, it is one of the requirements called upon by the quality assurance programs for the development, maintenance and utilization of the calculation codes used in safety analysis.

For the calculation of control rod worth the lattice code WIMS-D/4 [8] and the diffusion cod SNAP-3D [9] were used.

This work presents the obtained results and gives a comparison with the experimental values.

CRITICAL ASSEMBLY IPEN/MB-01 DESCRIPTION

The critical assembly IPEN/MB-01 is used for the study of the neutron characteristics of light water moderated systems. It serves to the verification of the calculation methods of different types of fuel elements and PWR type lattices as well as the worth of the control rods and the response to different reactivity insertions.

The study was performed for a cylindrical configuration of the IPEN/MB-01 reactor core. Figure 1 shows the studied reactor core configuration.

The Ag-In-Cd control group (BC) and B_4C safety group comprise 12 absorbent rods each. Their distribution is such that BS#1 and BC#1 groups are located on the North part and BS#2 and BC#2 groups are located on the South part and are show in the figure 2.

Figure 3 shows the geometric details of the fuel rods and the control rods used in the experiment.

Annex 1 shows the geometric data and isotopic composition of the fuel and control rods respectively and reflector data.

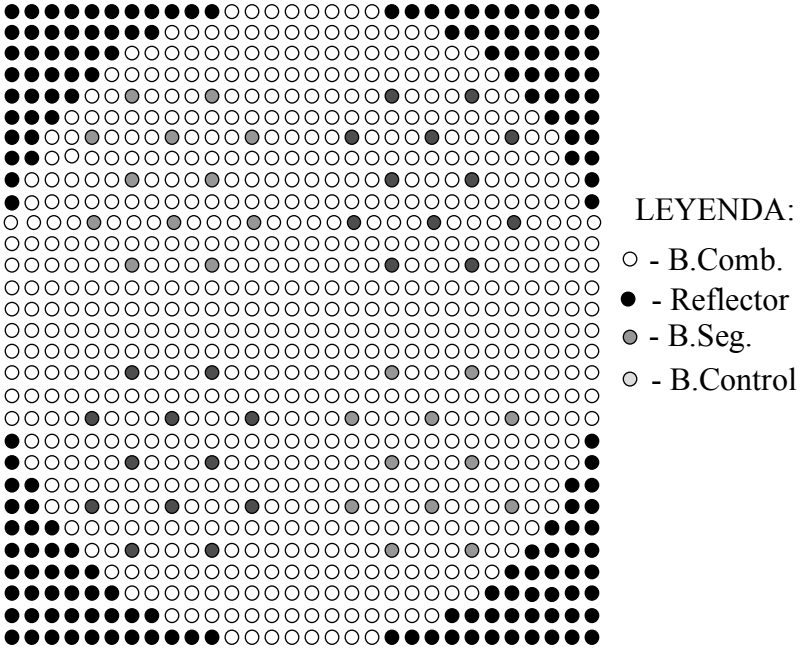


Fig. 1. The IPEN/MB-01 core with a cylindrical configuration.

Fig. 2. Schematic diagram of the distribution of control group, safety group and the compensated ionization chambers (CIC).

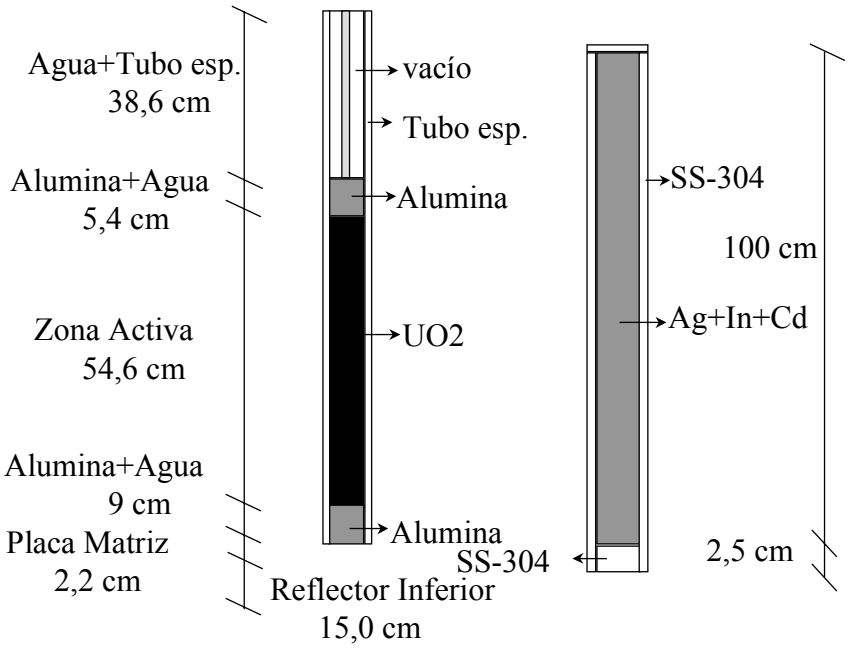


Fig. 3. Geometric details of the fuel rod and the control rod.

METHOD

The calculation methodology established in this paper is based on codes WIMS-D/4 [8] and SNAP-3D [9], which were used to determine the effective cross sections and the effective multiplication factors, respectively.

The spectral program WIMS-D/4 used the WIMS-IJS1 effective cross sections library [10], on a structure of 69 energy groups. The mentioned library contains effective sections for absorbing materials such as Ag, In and Cd. In the case of Indium the library includes only data on the In-115 isotope. For that reason a correlation was made on the In-115 nuclear density to have into accounts the In-113 isotope. The control rods were considered as black cell, calculating the effective extrapolation distance using the respective spectral calculation in a way that the flux-current relation on the cell boundary would remain constant.

For the calculation of the integral characteristic of the rods the SNAP-3D code was used. It was simulated the insertion of the rod and the K_{eff} value was determined for each position.

The work briefly exhibits the main approximations and calculation methods, emphasizing the selection of the physical and geometric methods for the calculation of the effective selections and other parameters needed for the calculation by few groups. This work comprises the results obtained and possible error sources.

CALCULATION O F THE CELL CONSTANTS

- Fuel cell

The IPEN/MB-01 fuel element together with the surrounding water layer was considered as the fuel cell for the calculation. The fuel cell is given in a form of concentric rings. It comprises 4 regions: fuel, air, SS-304 cladding and water. The real square geometry for the calculation of the lattice was cylindrized.

- Absorbent cell

The absorbent cells were calculated in the form of macro-cells, which comprised the absorber cell in the center and 8 combustible cell around.

The central absorbent cell comprises 5 zones: air, clad, water, SS-304 guide tube and water.

- Water hole

The constant values of the water cell in the active zone were obtained for a water zone surrounding a cylindrical nucleus using the "cluster" option and free boundary condition.

- Radial reflector

The reflector zone constant values were obtained for the water zone surrounding a cylindrical nucleus using the "cluster" option and the free boundary condition.

- Guide tube

For the determination of the guide tube constant values also used the supercell model locating the guide tube in the center and surrounding it with 8 fuel cells.

The discrete ordinate method S_{12} and 69 energy group was utilized in all the cases. The Bell and Dancoff factors were estimated through the option REGULAR 1 and the correction by escape was performed in B1 approximation. The constant values were condensed in two groups: 45 rapid group and 24 thermal group.

DIFUSION CALCULATION

The diffusion calculation was performed in 3 dimensions using the SNAP-3D program. The constant values of the fuel cells were taken directly from the calculation using WIMS-D/4. The control rods were considered as black cell, calculating the effective extrapolation distance using the respective spectral calculation in a way that the flux-current relation on the cell boundary would keep constant.

For the determination of the reactivity worth of the control rods, firstly calculated K_{eff} of the no perturbed zone and later calculated K_{eff} of the active zone with the introduced control rods.

For the calculation of the integral curve of the rods were introducing the rods and calculated the K_{eff} for each position.

The calculation was performed for 2 groups, considering the up scattering. We used a convergence criterion of 0.00001 and an internal and external maximum of iterations equal 300 for the determination of the flux distribution. For the calculation, we have assumed that the BC#1 and BC#2 rod groups would simultaneously move.

The diffusion theory does not provide exact results for sudden variations of the neutron flux density, within the limits of a strongly absorbing block, such as the control rods. However, the theory can be applied if we introduce the effective boundary conditions.

RESULTS

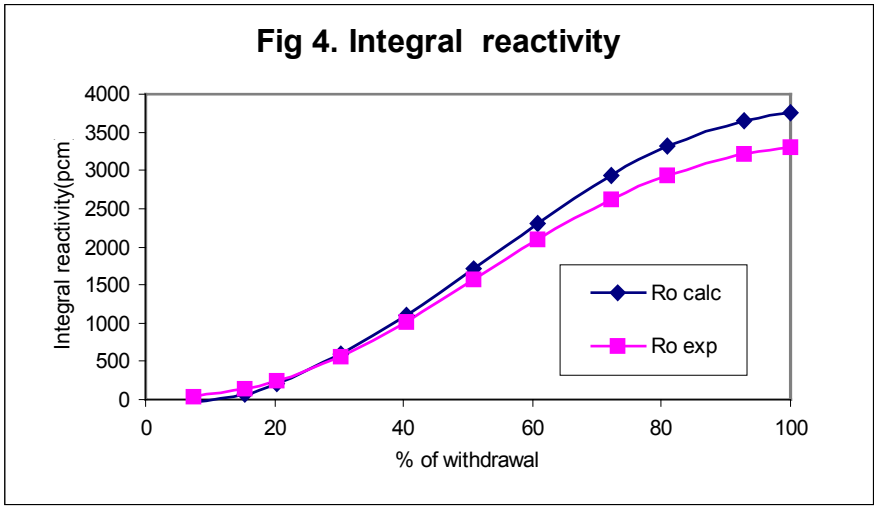
In Table 1, our results and those obtained experimentally at IPEN/MB-01 [11] are compared.

Table 1 – BC#1 integral reactivity values

% withdrawal	ρ_{calc}	ρ_{exp}	$\Delta\rho$ (%)	K_{eff} calc	K_{eff} exp	ΔK^{rel}(%)	ΔK^{abs}(pcm)
7.4	-39	41.33	-194.36244	0.99961	1.00041	-0.08029	-80.3318
15.3	65	139.81	-53.50833	1.00065	1.00140	-0.07485	-74.9634
20.4	201.12	244.31	-17.67835	1.00201	1.00244	-0.04327	-43.3830
30.3	588.77	559.92	5.15252	1.00592	1.00563	0.02902	29.18427
40.4	1106.88	1015.5	8.99852	1.01119	1.01025	0.09240	93.35076
50.9	1717.6	1572.19	9.24888	1.01747	1.01597	0.14795	150.31443
60.9	2311.47	2101.23	10.00556	1.02366	1.02146	0.21521	219.83383
72.2	2928.06	2620.33	11.74394	1.03016	1.02690	0.31701	325.54260
80.8	3312.74	2933.15	12.94137	1.03426	1.03021	0.39259	404.45906
92.9	3658.29	3217.13	13.71284	1.03797	1.03324	0.45791	473.13304
100	3747	3303.83	13.41382	1.03892	1.03416	0.46042	476.15330

The obtained results are in agreement with the experimental values reported in [11]. The deviations obtained with our methodology are less than 0.5%, which are in accordance to the generally accepted values that range from 5 to 7%.

In the figure 4 can see the deviation between the measured and calculated values.



From figure 4, observe how the deviation between the measured and calculated values raises as the percentage of rod withdrawal raises. This is probably because the errors are being cancelled.

CONCLUSIONS

As a result the calculation system formed by WIMS/D-4, SNAP-3D and the WIMS-IJSI library were validated for the calculation of the absorber rods.

The results shows that the methodology of calculation describing the absorber cells by the effective extrapolation distance gives the accuracy required for safety analyses.

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ANNEX

Table 2 – Geometric data for the fuel rod

ACTIV ZONE	
Fuel	UO_2
Pellet diameter	0.849 cm
Outer diameter of the clad	0.980 cm
Cladding thickness	0.060 cm
lattice pitch	1.500 cm
ALUMINIA ZONE	
Pellet diameter	0.849 cm
Cladding outer diameter	0.980 cm
Cladding thickness	0.060 cm
SPACER TUBE	
Inner diameter	0.730 cm
Outer diameter	0.849 cm

Table 3 – Geometric data for the control rod

Absorbing material	Ag-In-Cd
Absorbing diameter	0.832 cm
Cladding outer diameter	0.980 cm
Cladding thickness	0.060 cm
Guide tube outer diameter	1.200 cm
Guide tube thickness	0.035 cm

Table 4 – Isotopic composition of the fuel rod

Reflector

Water
Temperature = 20°C
Pressure = 0.99820 g/cm^3

CONCENTRATION (átomos/barn-cm)	
Fuel pellet	
U-235	1.00349E-03
U-238	2.17938E'02
O-16	4.55138E-02
Clad, Guide Tube	
Fe	5.67582E-02
Ni	8.64435E-03
Cr	1.72649E-02
Mn-55	1.59898E-03
Si	3.34513E-04
Pellet of Aluminia	
Al	4.30049E-02
O-16	6.45074E-02

Table 5 – Isotopic composition of the control rod

CONCENTRATION (átomos/barn-cm)	
Absorbens	
Ag-107	2.35462E-02
Ag-109	2.18835E-02
In-113	3.42506E-04
In-115	7.65996E-03
Cd	2.72492E-03
Clad, Guide tube, lower part	
Fe	5.67582E-02
Ni	8.64435E-03
Cr	1.72649E-02
Mn-55	1.59898E-03
Si	3.34513E-03