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THE SUB CRITICAL CORE OF IPEN-MB-01 DRIVEN BY A NEUTRON SOURCE IN THE FRAMEWORK OF THE IAEA COLLABORATIVE WORK ON LOW ENRICHMENT URANIUM(LEU) FUEL UTILIZATION IN ACCELERATOR DRIVEN SUB ASSEMBLY SYSTEM

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ABSTRACT

In the framework of the International Atomic Energy Agency(IAEA) Coordinated Research Projects(CRP) on i)Analytical and Experimental Benchmark Analysis on ADS and ii) Collaborative Work on Low Enriched Uranium Fuel Utilization., a benchmark was proposed to study the feasibility to introduce a compact neutron generator to produce a D-D and a D-T neutron source in a sub critical core of the Brazilian Zero Power Reactor, IPEN-MB-01, for two configuration, i) without control rods(phase I), ii) with control rods(phase II). Technical Specifications were distributed for the participants, in which a complete description of the facility was made as well as the tasks to be performed. Participated in this benchmark the following countries: Argentina, Brazil, China, Republic of Korea, and Spain.. The paper summarizes the motivation for the work, the description of the facility, the tasks to be performed, the results obtained by the participants up today, and the conclusions.

1. Introduction

A first Work shop on LEU Fuel Utilization in ADS Experimental Facilities took place at IAEA in 2005, where the concern of the US RERTR program and the IAEA (Nuclear Fuel Division) with the utilization of HEU in Source Driven Experimental Facilities was presented] A second workshop on "Low Enriched Uranium (LEU) Fuel Utilization in Accelerator Driven Sub- Critical Assembly (ADS) System", promoted by the Nuclear Fuel Cycle and Waste Technology, took place from 6 to 9 November 2006. During this Workshop, we present a paper on the utilization of a compact neutron generator to drive a sub critical core of the IPEN-MB-01 facility for reactor physics experiments, as a preliminary proposal to install a compact neutron generator developed by The Plasma and Ion Source Technology Group at the Lawrence Berkeley National Laboratory into a sub critical core of the Zero Power Facility, IPEN-MB-01, at Instituto de Pesquisas Energética e Nucleares, aiming to perform Reactor Physics benchmark measurements of source driven systems.[1]. This preliminary proposal becomes a benchmark in the collaborative work. Also it was in this workshop that the activities to be realized in the framework of the collaborative work were defined, and commitments were made by the interested participants: Argentina, China, Republic of Korea, and Spain. In short, we defined two phases as scope of the work, the first was a configuration without control rods, and the second with control rods partially inserted. The technical specifications for the facility and the tasks to be performed were distributed to the participants [2, 3]. Finally in the two last meetings, which were joint meetings with the Coordinated Research Project on Analytical and Experimental Benchmark Analysis on ADS , the first held in Rome, 12-16 November 2007, and the second in Vienna, 26-30 January 2009, progress reports were presented containing preliminaries inter comparisons among the participants. Here, we wish to report the results for this benchmark exercises obtained up today. The structure of the paper contains the description of the problem/facility; the preliminary results obtained by the participants (inter comparison) as well as a short summary of the methodologies used by them, and the conclusions obtained by solving this benchmark.

2. Description of the IPEN-MB-01 facility

The IPEN-MB-01 is a Zero Power Reactor (100 watts), light water tank type, consisting of a 28x 26 rectangular array of LEU UO_2 fuel pins, 4.3 w/o, with a clad of SS-304. The pitch (1.5 cm) was chosen to give an optimum moderator ratio. Figure 1, illustrates a pin of the IPEN-MB-01, and figure 2, illustrates an axial (A), and radial cross sections (B), of the facility.

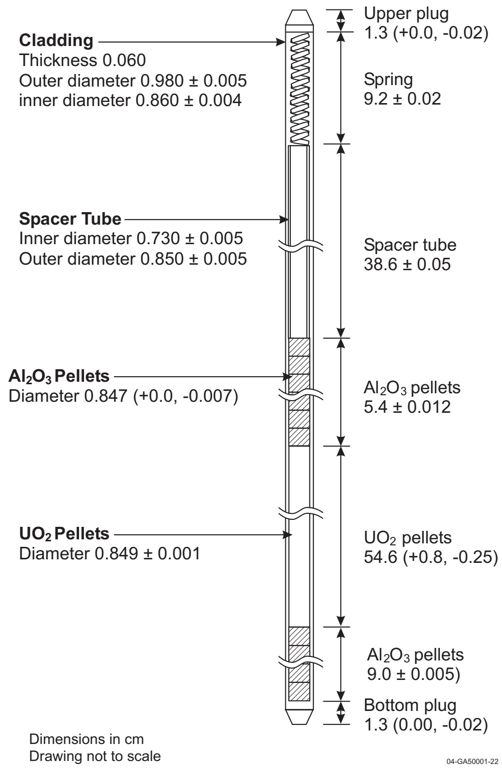
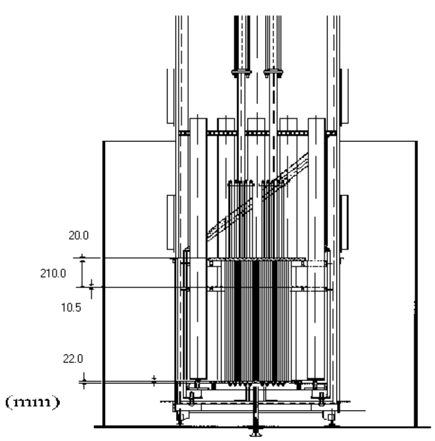
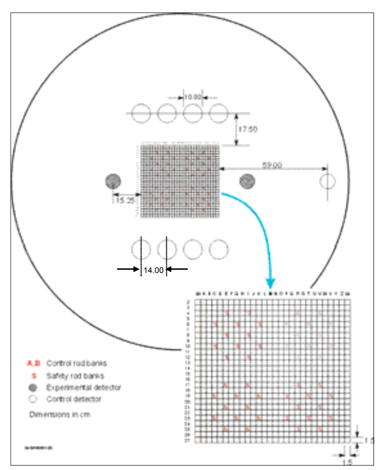


Figure1: IPEN-MB-01 Fuel Pin



(A)



(B)

Figure 2: Cross Sections of IPEN-MB-01: axial (A), and radial (B).

The facility is controlled by control banks (2), composed by 12 Ag-In-Cd pins. Also there are 2 banks of Safety Rods, composed by 12 B_4 C pins, which are kept out of the core. Geometrical data for the fuel pins, and control rod pins are show in Table 1. A complete description of the IPEN-MB-01, can be find in the NEA/NSC/DOC (95)03/IV [2], since the facility is in the International Reactor Physics Evaluation Project.

3. Benchmark Exercise Description

The benchmark exercise was divided in two parts:
BENCHMARK-PHASE I: Sub Critical Core without control rods, one point source

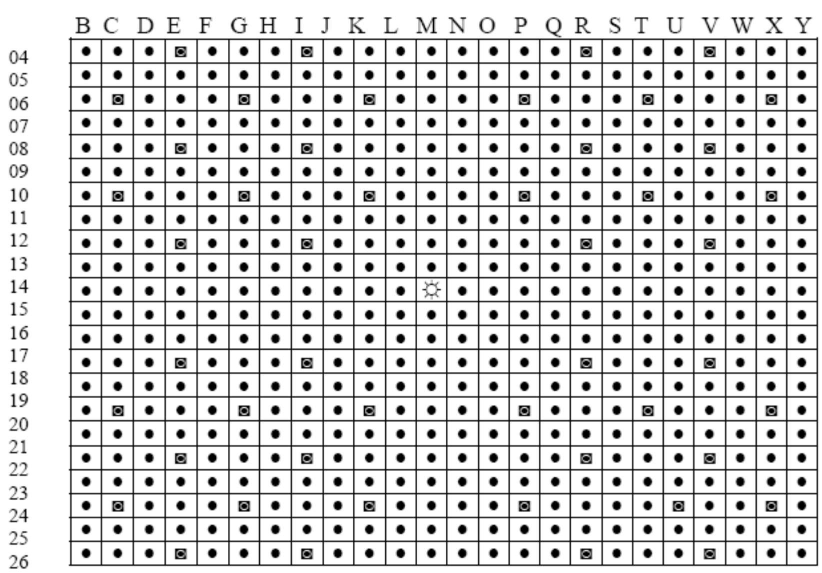
Within the framework of the collaborative work on the utilization of LEU in ADS, we consider in phase 1 exercise the analyses of a sub critical configuration of the IPEN-MB-01, by removing all control rods, and two rows and lines of the critical configuration, with a point source D-D (E= 2.45 MeV), and D-T (E=14.1 MeV), isotropic and mono energetic, located in the position M14 (see Fig. 3). The tube guide of the source is to be considered as an empty space. The positions of the control and safety rods are to be considered as tube guides filled with water. The matrix considered for the exercise is a configuration (24x 22) positions in the matrix, as illustrated in figure 3.
The parameters requested in the benchmark specifications, and evaluated by the participants, are listed below

Phase 1:

- Static Parameters: a) Keff, ks, b) total flux distribution axially averaged in each cell, in the active fuel length of the sub critical configuration, c) total power, total flux at the experimental detectors, c) Neutron spectra (averaged in spaced) at cells (N,14) (R,14) (P,10) (O,11) (R,8), d) axial distribution of the total flux at the same cells as in the previous item in c in the complete rod (active and non active)
- Dynamic and kinetics Parameters: Given a rectangular pulse of 10 μs width, and with amplitude 10 times the CW, calculate: a) the time evolution of the total flux in the x position 14, starting from the source position up to the experimental detector for t=50, 102, 103, 104, 105,106 μs. b) Calculate at the detector position, plot the total flux (counts) versus time, c) using this data estimate ρ [$] using the area method.

Table 1: Geometrical Data of IPEN-MB-01

Active Region	
Fuel	UO_2
Diameter	0.84894 cm
Cladding Outer Diameter	0.98074 cm
Cladding Thickness	0.06164 cm
Pitch (Square)	1.5037 cm
Alumina Region	
Diameter	0.847 cm
Cladding Outer Diameter	0.98074 cm
Cladding Thickness	0.06164 cm
SS Spacer Tube Region	
Inner Diameter	0.730 cm
Outer Diameter	0.850 cm
Control Rod Data	
Absorber Material	Ag-In-Cd
Absorber Diameter	0.832 cm
Outer Cladding Diameter	0.98074 cm
Cladding Thickness	0.06164 cm
Guide Tube Outer Diameter[(a)]	1.200 cm
Guide Tube Thickness[(a)]	0.035 cm
Bottom Grid Plate Dimensions	
Square Side	58.8 cm
Thickness	2.2 cm



● : Fuel Rod
◙ : Guide Tube (filled with water)
☼: Source

Figure 3: Matrix Sub Critical configuration for phase I

In the phase II, we are proposing to calculate the parameters described for a configuration typically used for critical measurements consisting of a 28x 26 rectangular array of UO2 fuel pins, 4.3 w/0, with a clad of SS-304. For this Configuration, the reactor is controlled by inserting the control rods. In this phase we are considering that the reactor would be sub critical by keeping fix one bank (BC1) half height inserted, and find several degrees of sub criticality by moving the second bank. Then for each degree of sub criticality a point source will be inserted in the position (L14), and for each degree of sub criticality, static and kinetics parameters will be calculated.
Figures 1 and 2, define the phase II configuration. The BC1 and BC2 symbol referrers to the control bank consisting of 12 Ag-In-Cd rods each. The control bank position is given in % withdrawn, being the reference level or 0% when the bottom of the active absorber length (excluding the bottom plugs) is aligned with the bottom of the active core. During the reactor operation both the safety banks are 135% withdrawn, and could be neglected.

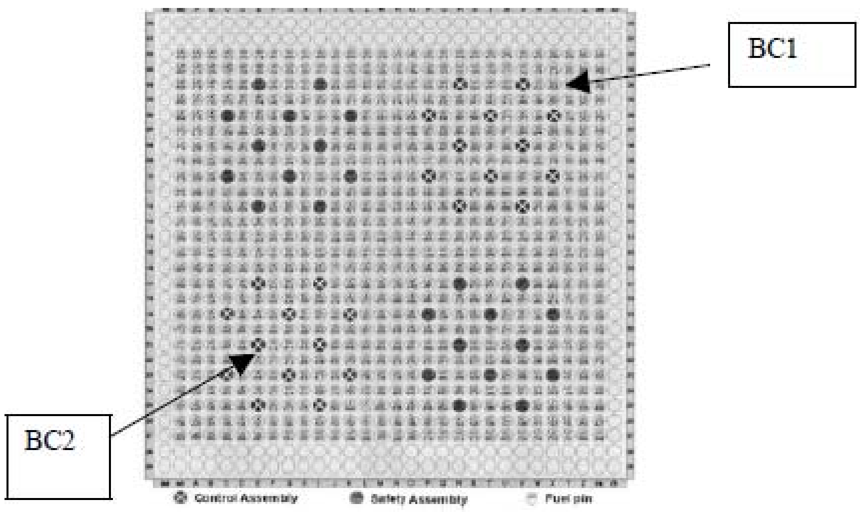


Figure 4: Phase II configuration (radial)

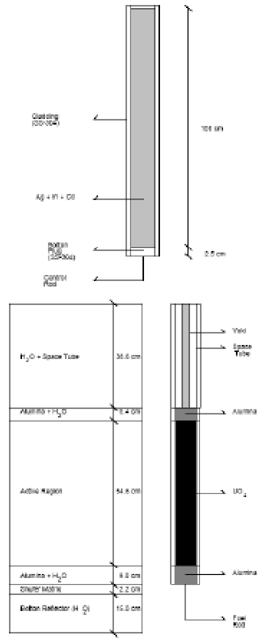


Figure 5: Axial View of the IPEN-MB-01 core (schematic)

The tasks to be performed are defined as:

1. Without source, calculate the keff versus the position of BC1, keeping BC2=50%.
2. ks(source multiplication factor), with the source for keff=0.9990,0.9900,0.9800.
3. Total Power (CW): $P=\iint dE dV \Sigma f(r,E)\varphi(r,E)$ fissions/sec for Keff=0.9990, 0.9900, 0.9800.
4. The Integral Kinetics Parameters (ρ, β, Λ) for Keff=0.9990, 0.9900, 0.9800.

4. Results

The results obtained by the participants were obtained using the following libraries and codes:

- Argentina (A. Cintas, E. Lopasso, J. Ignácio-): ENDF/B-VI & V,/ MCNP5
- Brazil (T. Carluccio, J.R. Maiorino): ENDF/B-VII & MCNP5 1.4
- China(Xia Pu): MCNP/ ENDF/B-VI
- Republic of Korea(Ho Jin Park & Chang Hyo Kim): ENDF/B-VII/ McCARD
- Spain(F. Sordo, A.Abanades): ENDF/B=VI/ MCNPX

Tables 2 and 3 show the integral parameters for phase 1 and 2, respectively .It is important to emphasis that still some results are on going, mainly for phase II, and are preliminary. Final results will be available at the end of the collaborative work.

Table 2: Integral Parameters for phase I(statics and dynamics)

	Argentina				Brazil				China				ROK				Spain			
Keff	0.96908	1.10E-04			0.97233	0.00025			0.96883	0.00022			0.97227	0.00016			0.9738	0.0017		
Beta eff	788	15			755.9162	28.80758							0.00757	0.00003			0.006048			
	DD		DT		DD		DT		DD		DT		DD		DT		DD		DT	
	value	σ	value	σ	value	σ	value	σ	value	σ	value	σ	value	σ	value	σ	value	σ	value	σ
Ks	0.96953	1.04E-04	0.96581	3.25E-04	0.964409	0.000377	0.961727	0.000452	0.9928		0.992		0.97492	4.02E-03	0.97572	4.02E-03			0.972261	0.0139
Total Power	2.13E+01	1.00E-01	1.87E+01	1.00E-01	18.569397	0.0035	16.50472	0.062718					18.43607	0.076002	16.56214	0.086123			20.39611	
Flux Detector 1	2.90E-04	2.6E-06	2.60E-04	6.0E-06	5.78E-04	0.006	5.47E-04	0.01	2.43E-04	0.0125	2.25E-04	0.0045	4.64E-04	4.280E-03	4.43E-04	4.140E-03			0.001746	0.0204
Flux Detector 2	5.44E-04	4.5E-06	4.98E-04	1.0E-05	1.115E-03	0.005	1.03E-03	0.01	1.97E-04	0.0127	1.71E-04	0.0046	6.18E-04	4.150E-03	5.78E-04	3.980E-03			0.001474	0.021
Flux Detector 3	1.87E-07	3.7E-08	5.55E-07	1.6E-07	6.8E-07	0.129	1.18E-06	0.13	2.38E-05	0.0161	4.03E-07	0.0552	5.29E-07	7.235E-02	9.83E-07	6.229E-02			7.12E-07	0.5869
reactivity	-3063	60	-2905	79																
Λ	33	1	33	1	35.782543	26.24018	35.78254	26.24018					36.93	0.02	36.93	0.02				

Table 3: Integral Parameters for phase II (statics and dynamics)

	Argentina				Brazil				China				ROK			
	DD		DT		DD		DT		DD		DT		DD		DT	
	value	σ	value	σ	value	σ	value	σ	value	σ	value	σ	value	σ	value	σ
0.999																
Ks	0.99855	4.67E-05	0.99834	4.89E-05												
Total Power	486.60	15.70	425.80	12.60												
reactivity	-152	6	-105	5												
Beta	809	14	809	14	733	12	733	12								
0.990																
Ks	0.98958	9.28E-05	0.98850	8.51E-05												
Total Power	67.10	0.60	60.50	0.40												
reactivity	-991	25	-922	31												
Beta	779	14	779	14	733	12	733	12								
Λ	31	1	31	1												
0.980																
Ks	0.97901	9.66E-05	0.97765	8.72E-05												
Total Power	32.90	0.20	30.70	0.10												
reactivity	-2086	56	-2016	73												
Beta	791	14	791	14	733	12	733	12								
Λ	33	1	33	1												

Figures 6 and 7 report the results for the flux map for the phase I. We would like to emphases that these results are not final yet. Also we did not report the results obtained by Spain, due to they are still in analysis. The results for phase II are also still in analysis, and will not be reported here.

The neutron spectrum for positions N-14, P-10, R-8, and R-14 are illustrated in Figure 8 for D-D reaction (phase I). Although we have the results for D-T source they are discrepant, and are under investigation. Also the results for phase II, are in analysis. Finally, in the Figures 9 and 10 we illustrate the results for the axial flux distribution for selected positions, for phase I.

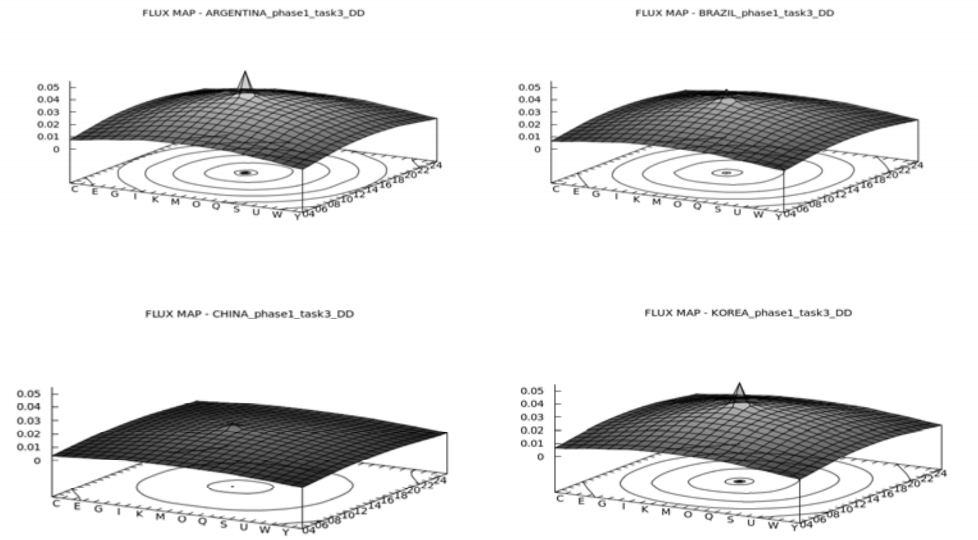


Figure 6: Flux Map for Phase I (D-D)

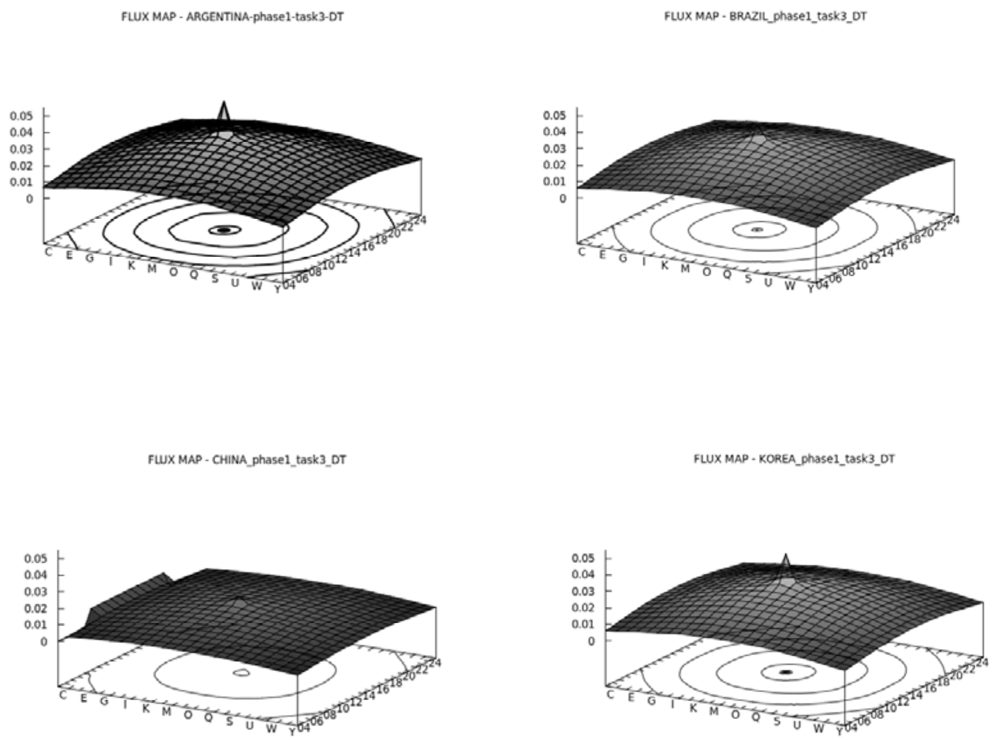


Figure 7: Flux Map for Phase I (D-T)

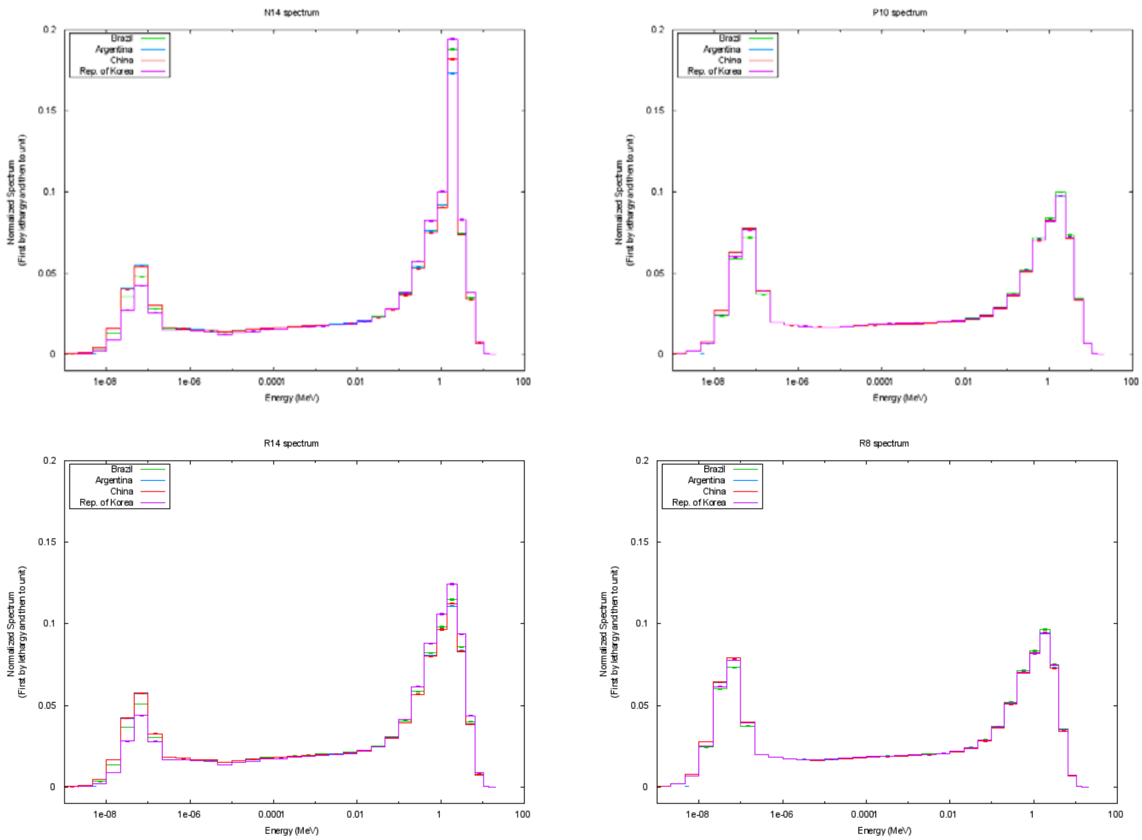


Figure 8: Neutron Spectrum –D-D (Phase I) in the positions N-14; P-10, R-8, R-14

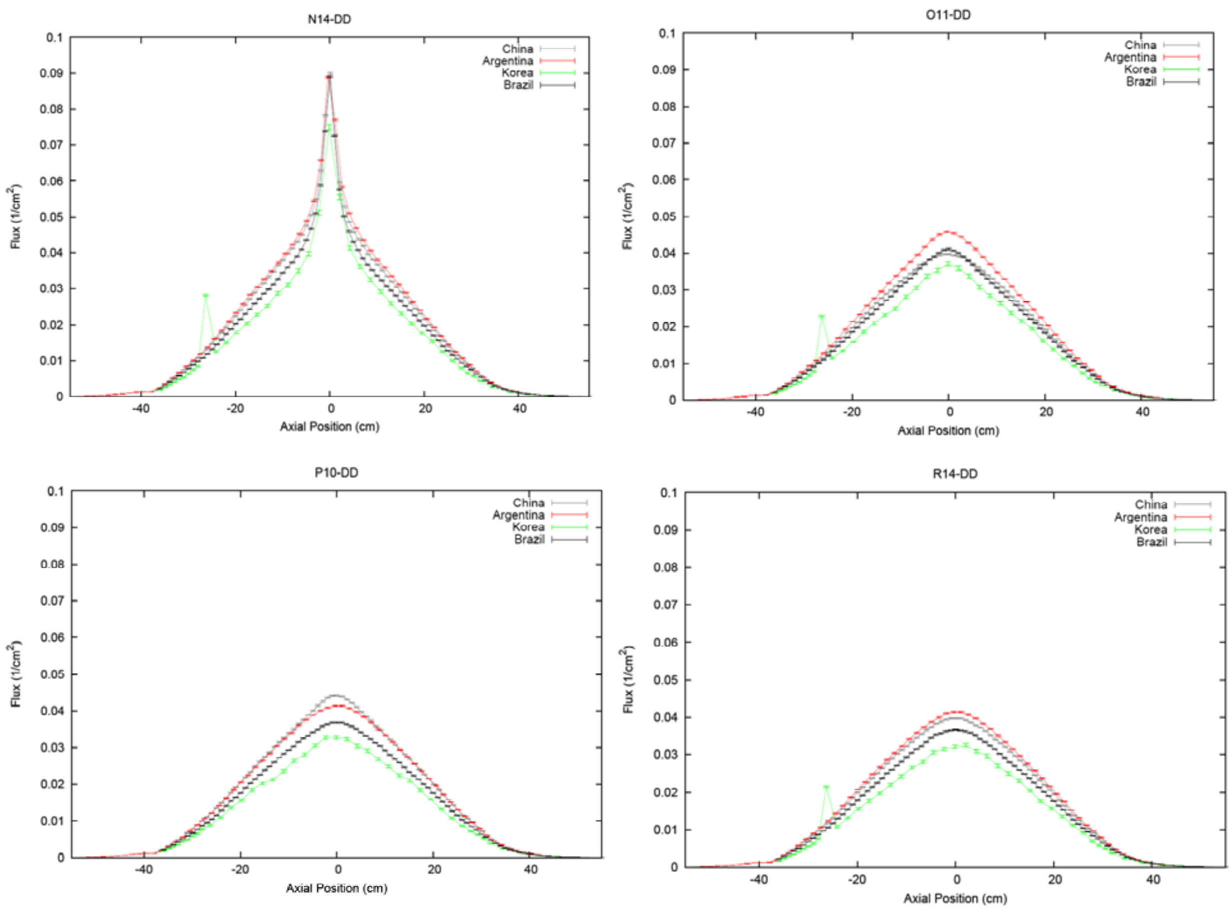


Figure 9: Axial Flux Distribution at selected positions. D-D Source- Phase I.

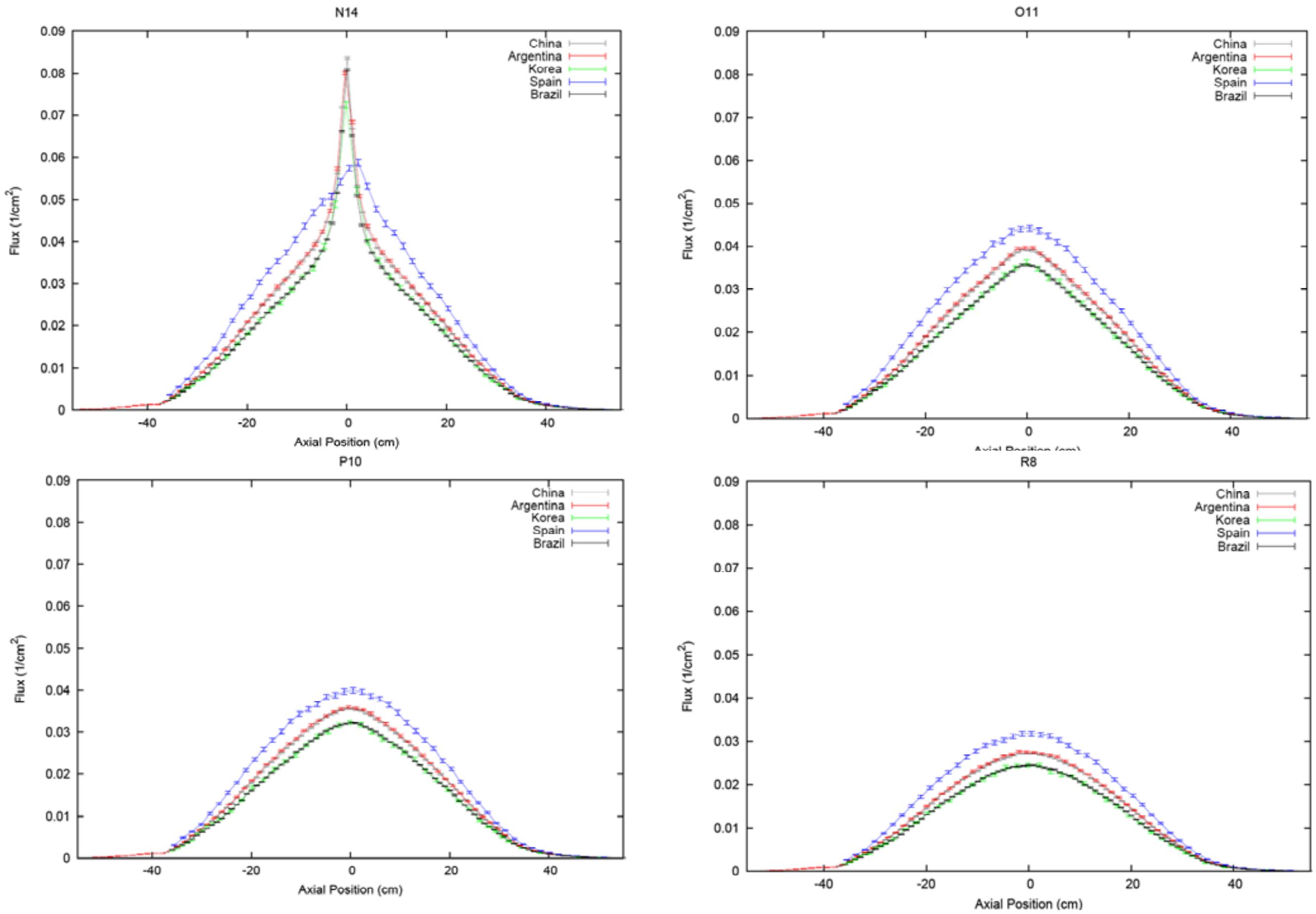


Figure 10: Axial Flux Distribution at selected positions. D-T Source-Phase I.

4. Analysis and Conclusions

Although the benchmark exercise is still on going, the results obtained up today allow some preliminary conclusions. First, it is clear that the inter comparison made, allows us to conclude that the integral parameters, such as k_{eff} are in relative good agreement up to 2 significant figures (e.g. for phase I, we may guaranty that K_{eff}=0,97), however k_s still have a discrepancy among the participants, indicating clearly that source driven system are not yet a well established benchmark, and need further investigation. For integral parameters such as power, there are a good agreement between Brazil and Korea, for instance the total power in fissions per source neutron/s, was obtained 18.6(D-D), and 16.5(D-T) by Brazil, and 18.4(D-D), and 16.4 by Korea, whereas Argentina obtained 21.3 and 18.7 respectively, indicating a systematic deviation. The results of China and Spain need to be reviewed. Moreover, the total flux at the experimental neutron detector positions in n/cm^2 per source neutrons/s, are also in agreement among the participants (~5x10^{-4}). These two parameters with the k_{eff}, are the bases to establish the feasibility to introduce a neutron source in a sub critical core of the IPEN-MB-01. Thus, we may conclude that it is feasible to turn IPEN-MB-01 in a sub critical experimental facility driven by a neutron generator which produces 10^8-10^9 n/s, quite common in now days. Then, the total power would be of the order of mile Watts, below of the cooling capability (100 W) of the critical system, and the fluxes in the experimental positions will be ~ 10^4-10^5 n/cm^2.s inside the range of the neutron detection.

5 References

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