The utilization of a compact neutron generator to drive a sub critical core of the IPEN-MB-01 facility for reactor physics experiments

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Abstract. This paper will show 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. Introduction

Experimental Measurements at Zero Power Facilities (Critical or Sub Critical Driven by Source) are fundamental to benchmark Reactor Physics Calculation Methods as well as Nuclear Data Base. Recently with the development of Accelerator Driven System for transmutation of High Level Waste, many facilities are being built or planned, for experimental benchmark of calculation methods of source driven systems, such as the MUSE experiments in the MASURCA facility at CEA-Cadarache in France[1], YALINA in Belarus[2], KURRI, in Japan[3] etc.

The Brazilian Facility IPEN-MB-01 is a zero power (100 W) assembly, with a flexible core made of fuel pins of LEU (4.3w/o), UO_2, in a square pitch configuration, which allows measurement of Reactor Physics parameters, such as flux distribution, reactivity, integral parameters, neutron spectrum etc. Although, originally designed with a critical core controlled by rods, it easily can be made sub critical by changing the control rod position, or the number of fuel pins in the core.

The Plasma and Ion Source Technology Group at the Lawrence Berkeley National Laboratory, developed a pulsed compact neutron generator (D-D, D-T or the T-T fusion reaction), which easily could be inserted into a sub critical core of the IPEN-MB-01. Coupling the compact pulsed neutron generator with the sub critical core, will allow extending the type of reactor physics experiments to be performed in the IPEN-MB-01, mainly kinetics parameters measurements.

This paper will show a proposal to develop a project to install a compact neutron generator in a sub critical core of the IPEN-MB-01, in order to develop an experimental LEU source driven facility, mainly for source driven sub critical kinetics or dynamic studies, which would be used as a regional or international benchmark facility.

2. Description of the IPEN-MB-01 Zero Power Facility

The IPEN-MB-01 is a Zero Power Reactor(100 watts), light water tank type, consisting of a 28x 26 rectangular array of UO_2 fuel pins, 4.3 w/0, 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.

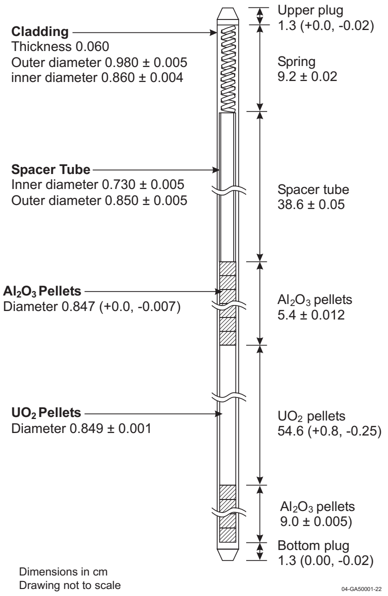
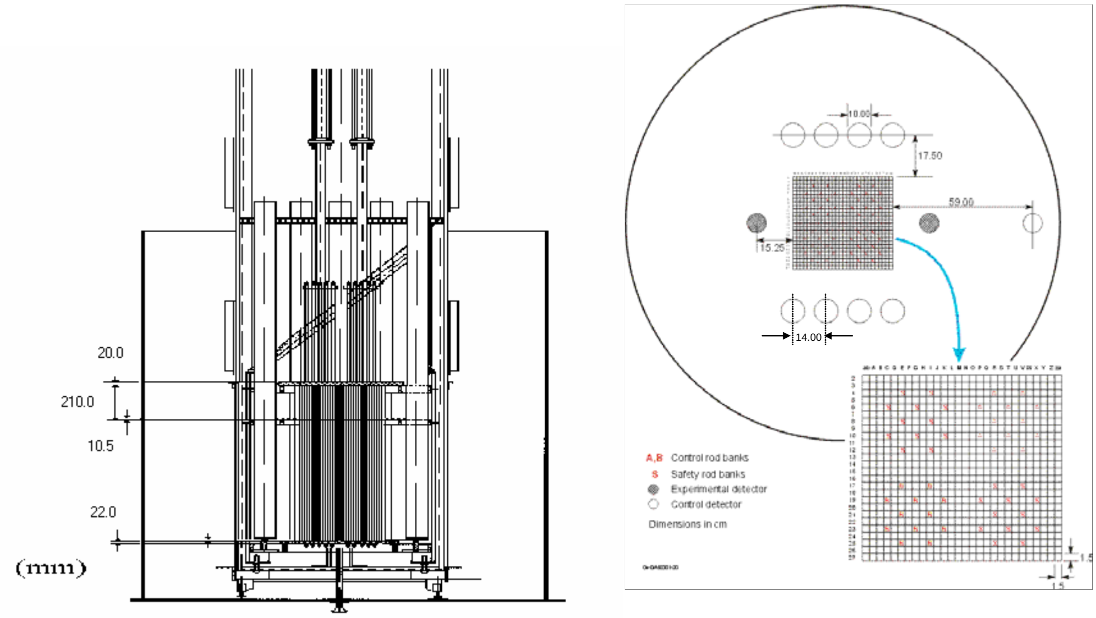


Figure1: IPEN-MB-01 Fuel Pin



(A) (B)

Figure2. 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 B4C 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 [4], since the facility is in the International Reactor Physics Evaluation Project.

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

3. Compact Neutron Generator: Design and Operation

The Plasma and Ion Source Technology Group at the Lawrence Berkeley National Laboratory (LBNL) has been developing compact neutron generators for over ten years. The neutrons in these generators are produced by the D-D, D-T or the T-T fusion reaction. All these neutron generators consist of three major components; an ion source, an electrostatic accelerator and a Ti target. By using 13.5 MHz RF induction discharge, the ion source is capable of producing high current density with atomic deuterium or tritium ion percentage greater than 90%. With such high atomic ion percentage, the generators can be operated at lower beam energy (~100 keV) and produce higher neutron flux than the commercial neutron sources. Depending on the application, the Berkeley Group has developed various types of compact neutron source [5]. Axial type D-D neutron generators have replaced radioactive sources for PGAA and NAA and educational training. Coaxial type high flux D-D neutron sources have been built for boron neutron capture therapy in cancer treatment. A short-pulse small point T-T neutron source is now being developed for explosive detection. We are now planning to use a specially design axial neutron generator to drive a sub-critical core of the IPEN-MB-01 Zero Power Facility.

The ion source is a cylindrical chamber surrounded with permanent-magnets for plasma uniformity and confinement. The antenna is a copper coil located on the external surface of the chamber. The RF power is coupled into the plasma through a quartz or ceramic window. The plasma is produced by 13.5 MHz RF induction discharge. For 2 kW of RF input power, the plasma source can provide ion current density ~ 50 mA/cm^2 with atomic ion species percentage higher than 90%. The entire neutron generator is first pumped down to a low base pressure. It is then filled with pure deuterium gas for D-D neutron production or it can be filled with 50% deuterium and 50% tritium gas for D-T neutron formation. The lifetime of the generator can be tens of thousands of hours for pure deuterium operation and can be hundreds of hours for D-T operation. After that, the generator has to be refilled with deuterium and tritium gas again

If the diameter of the exit aperture is 5 mm, the extracted beam current will be approximately 10 mA. The electrostatic accelerator column will inject a 100 keV deuterium or a mixture of deuterium and tritium ion beam onto a Ti target located at the center of the reactor. With the accelerator column properly designed by an ion optics code, the ion beam can be steered accurately onto the Ti target. Ti is used as the target material because it can absorb deuterium or tritium atoms efficiently. The ion beam will implant deuterium or tritium into the Ti target. As the target temperature increases, the D or T atoms will diffuse back to the surface of the Ti. As more beam ions impinge on the Ti target, either the D-D, T-T or the D-T fusion reaction will occur and thus neutrons are produced. The Ti target can be cooled by the surrounding water in the reactor tank. To achieve optimum neutron output, the average ion beam power density on the Ti target is normally kept below 1 kW/cm^2. Figure 2, illustrates a typical axial neutron generator:

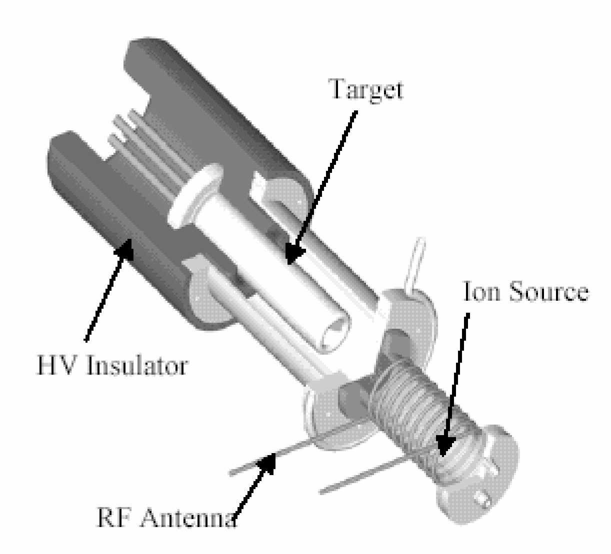


Figure 3; Schema of a typical Axial Neutron Generator

4. Coupling the Neutron Generator with a sub critical core

The first proposal is to replace a central fuel pin by a narrow beam. A neutron source of D-D reaction produces 2.45 MeV neutrons while the D-T reaction produces the 14 MeV neutrons. The T-T reaction generates neutrons with energy range from 0 to 9 MeV. For 100 kV, 10 mA beam power, the D-D neutron output is ~ 2 x 10^9 n/s. The cross-section for D-T reaction is about two orders of magnitude higher. For the same beam power, the D-T neutron output is ~ 3 x 10^{11} n/s. The cross-section for the T-T reaction is the same as that of D-D except that each T-T reaction produces two neutrons. The neutron generator can be operated either in cw or pulse mode by programming the RF power supply. For pulse beam operation, the pulse width and repetition rate can be adjusted by controlling the RF input power. The peak ion beam current and therefore the number of neutrons generated in each pulse can be much higher than the cw values for the same average beam power. If higher neutron fluxes are needed, one can replaced more fuel rods with beam pipes. With twelve beams, a total beam current of 120 mA can be obtained. The output flux of D-D neutrons will be 2.4 x 10^{10} n/s and that of D-T neutrons will be 3.6 x 10^{12} n/s.

With the ion source located outside the reactor tank and the target and beam pipe biased at ground potential, operation of this type of neutron generator is safe. It requires no modification of the existing facility structure and it has a small foot-print. Unlike most commercial neutron generators, the neutron pulses of this RF-driven neutron source are very reproducible and have very fast fall time (≤ 1 μs). Figure 4, illustrates the proposed concepts.

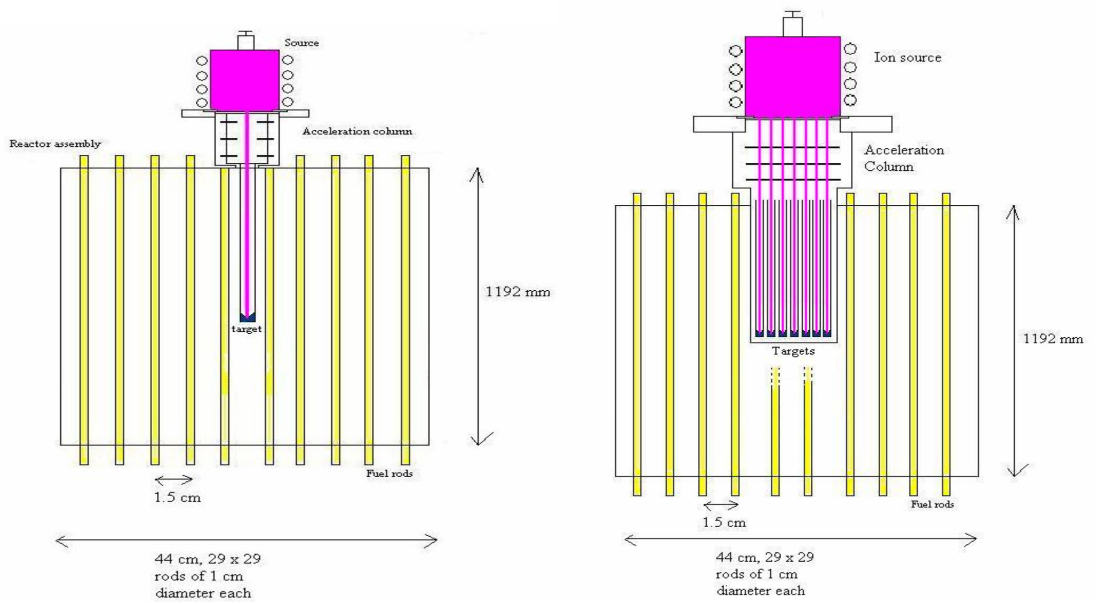


Figure 4: Schematic proposal to insert the neutron generator in the sub critical core of the IPEN-MB-01 facility.

A sub critical core could be achieved by moving control rods, or by geometrical configuration without control rods. Thus a preliminary calculation using MCNP-5[6], for a 24x22 configuration gives k= 0.97, and a total flux out of core ~10-3 cm-2 per neutron source intensity(D-T). Figure 5, illustrates a typical MCNP out put for such configuration.

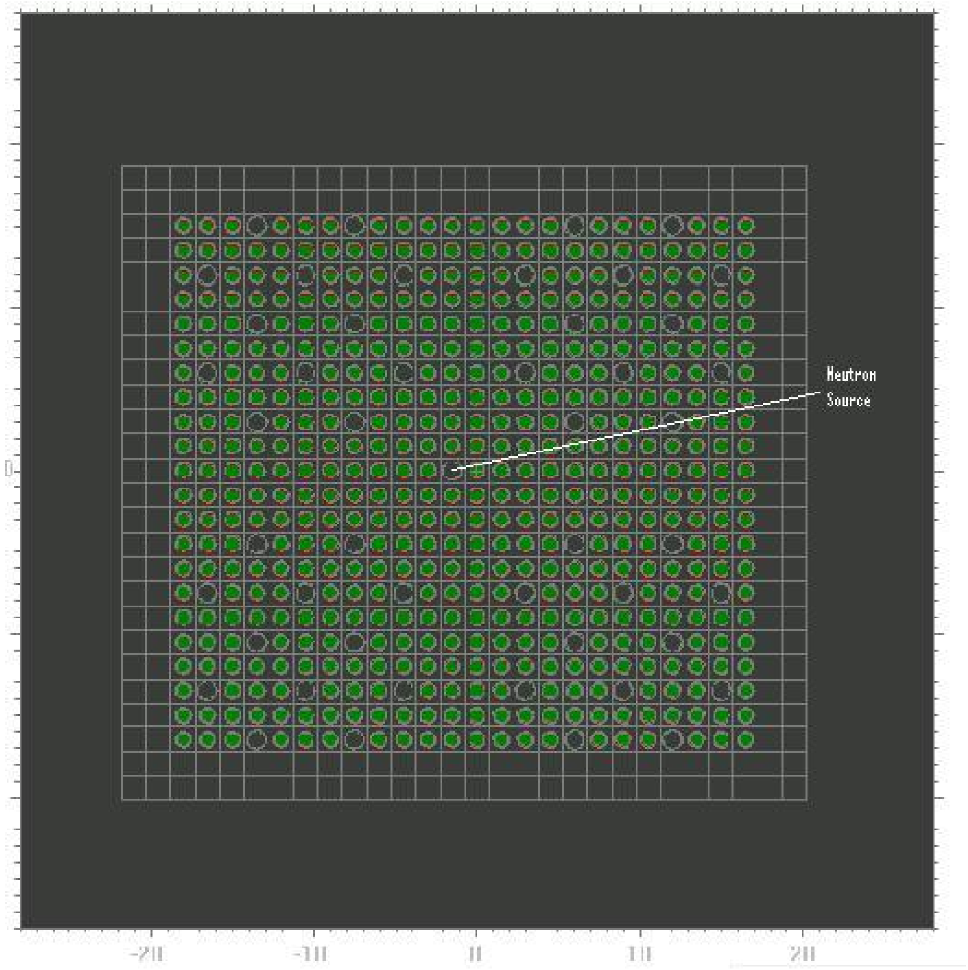


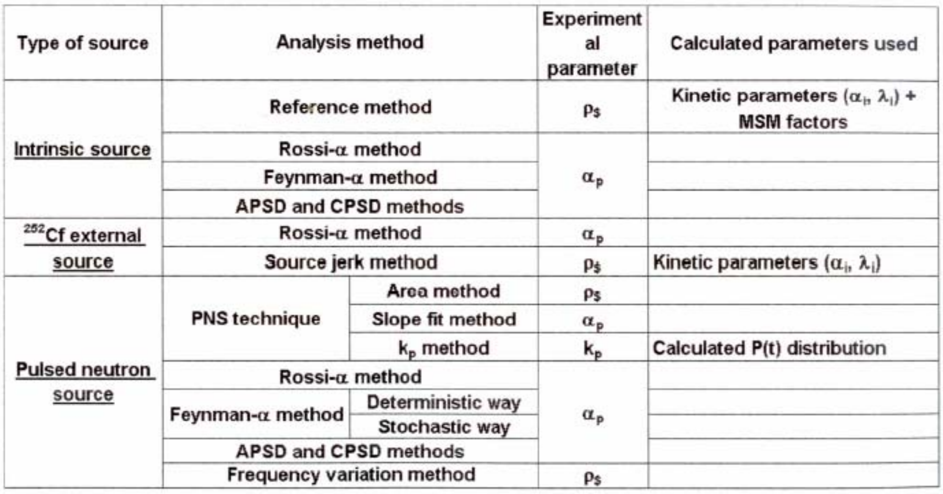
Figure 5: (24x22) sub critical configuration (k=0.97)

5. Experimental program

Since its first criticality in 1988, the IPEN-MB-01 has been used for several reactor physics measurements, such as determination of the spectral index, reactivity coefficients, critical kinetics parameters, spectrum, flux etc. Bitelli[7] summarized the main experiments realized in the facility. Recently, absolute measurements of kinetic parameters in sub critical configuration using a fixed neutron source had been reported by Kuramoto [8]. Now days the facility is in the NEA International Reactor Physics Evaluation Project (IRPhE).

By coupling the pulsed neutron generator with a sub critical configuration of the IPEN-MB-01, will allow to extend the possibilities of measurements to be performed in the facility, mainly the physics of the sub critical core driven by source. Table 2 shows a list of possible experiments which could be realized by inserting the neutron generator in the sub critical core.

Table 2: Kinetics Parameters measurements in a sub critical source drive system



Type of source	Analysis method		Experimental parameter	Calculated parameters used
Intrinsic source	Reference method		$\rho_\$$	Kinetic parameters (α_i, λ_i) + MSM factors
	Rossi-α method		α_p	
	Feynman-α method			
	APSD and CPSD methods			
^{252}Cf external source	Rossi-α method		α_p	
	Source jerk method		$\rho_\$$	Kinetic parameters (α_i, λ_i)
Pulsed neutron source	PNS technique	Area method	$\rho_\$$	
		Slope fit method	α_p	
		k_p method	k_p	Calculated P(t) distribution
	Rossi-α method		α_p	
	Feynman-α method	Deterministic way		
		Stochastic way		
	APSD and CPSD methods			
	Frequency variation method		$\rho_\$$	

6. Conclusions

By inserting the compact neutron generator developed by Berkeley in a sub critical core of the IPEN-MB-01, would increase the experimental utilization of the facility, mainly those related with kinetics of source driven system, which still has some open questions, as reported recently by Dulla et all[9]. Moreover, such proposal would demonstrate that good physics could be made using LEU, source driven systems. Finally, once the proposal becomes a reality, it could be a benchmark excellence facility, mainly for the Latin America region, and therefore increasing the human power and knowledge in the region.

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