Start-up Characteristics of the YALINA- Booster Subcritical Assembly

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YALINA-Booster assembly consists of fast and thermal zones with a one directional coupling between them. The fuel materials of the fast zone are metallic uranium (90% enrichment) and uranium oxide (36% enrichment) and the fuel rods are loaded in lead metal. The thermal zone has uranium dioxide fuel (10% enrichment) and polyethylene moderator. Between the two zones boron carbide and natural uranium rods are used to provide the one directional coupling between the two zones. Graphite reflector is used around the thermal zone. The assembly design and operation satisfies all the safety rules for operating nuclear facilities.

The fuel was loaded in small steps and the multiplication factor has been measured for each step. The reciprocal counting method and the pulse neutron source technique have been used. The experimental results obtained during the start-up of YALINA-Booster are presented and discussed in the paper.

1. INTRODUCTION

Important safety issues of Accelerator Driven Systems (ADS) are the on-line monitoring and control of reactivity changes during normal start-ups, steady state operation, and fuel replacement and re-arrangement operations. The system subcriticality level can not be measured directly, therefore indirect parameters are measured to determine the system reactivity. Pulsed neutron sources are utilized for driving the subcritical assemblies and the produced neutron fluxes are measured as a function of time during the pulse. Several methods can utilize the measured neutron flux to predict the system reactivity. The neutron flux changes during the pulse reveals the neutronics characteristics of the system.

YALINA-Booster subcritical assembly[1,2] is driven by a neutron generator. The pulse neutron source (PNS) area method has been applied for reactivity determination during the loading procedure in conjunction with the conventional reciprocal counting method. The PNS method has been chosen because of the available experimental equipment and the previous experience using this technique. The choice was also encouraged by the successful utilization of this method at various nuclear installations, including the MASURCA facility.[3]

This paper describes the start up characterization of the YALINA-Booster subcritical assembly. The experimental results measured during the fuel loading are presented. Both, the reciprocal counting method and the PNS area method were used.

2. YALINA-BOOSTER DESIGN AND INSTRUMENTATION

The YALINA-Booster subcritical assembly is a part of YALINA facility as shown in Figure1. It consists of coupled fast and thermal multiplying zones driven by an external neutron source[1,2]. The neutron source is obtained from a deuteron accelerator and water cooled target with a diameter of 45 or 230 mm. The maximum neutron yield is 2.3×10^{10} n/s for the deuterium target and 10^{12} n/s for the tritium target.

The YALINA-Booster subcritical assembly is aligned horizontally, as well as the deuteron beam tube. The assembly consists of fast and thermal zones as shown in Figure 2. At the center, there is a square lead zone with dimensions of 78×78×645 mm. When the small target is used, the deuteron beam tube is located inside the lead zone. The target is located at the center of the core.

The fast zone is a rectangular parallelepiped shape with dimensions of 480×480×645 mm. It is composed of tightly packed lead subassemblies with fuel rods arranged in a square lattice. The fuel rod spacing of the fast zone is 11.143 mm in the inner part and 16 mm in the outer part. The fast zone is fueled with uranium metal rods with 90% ^{235}U enrichment in the inner part, uranium dioxide with

36% [235]U enrichment in the outer part. There are four experimental channels in the fast zone, EC1B-EC4B.

At the outer boundary of the fast zone, an absorber (valve), zone is located, consisting of an inner layer of 108 natural metallic uranium rods and the outer layer of 116 B_4C rods. This zone allows fast neutrons to enter into the thermal zone from the fast zone, but it prevents the thermal neutrons of the thermal zone from entering the fast zone. Consequently, a one way neutron coupling between the fast and the thermal zones is established. The thermal zone surrounds the absorber zone and it consists of 108 polyethylene subassemblies, each having 16 holes for loading EK-10 fuel rods. Uranium dioxide with 10% ^{235}U enrichment is used for the EK-10 fuel and magnesium oxide is employed to bond the fuel to the aluminum alloy clad. There are three experimental channels in the thermal zone, EC5T-EC7T. The thermal zone is surrounded in the radial direction by a 250 mm graphite reflector. There are three experimental channels in the reflector zone, two axial (EC8R, EC9R) and one radial (EC10R). In the axial directions along the fuel axis borated polyethylene blocks are used as a neutron reflector and biological shield.

The stand of the YALINA-Booster subcritical assembly can be positioned within ± 1mm in the X, У, or Z directions. This design flexibility provides the opportunity to have different subcritical configurations. The deuteron accelerator can operate both in continuous and pulse mode with pulse duration from 0.5 up to 100 μs and pulse repetition frequency from 10 Hz to about 10 kHz.

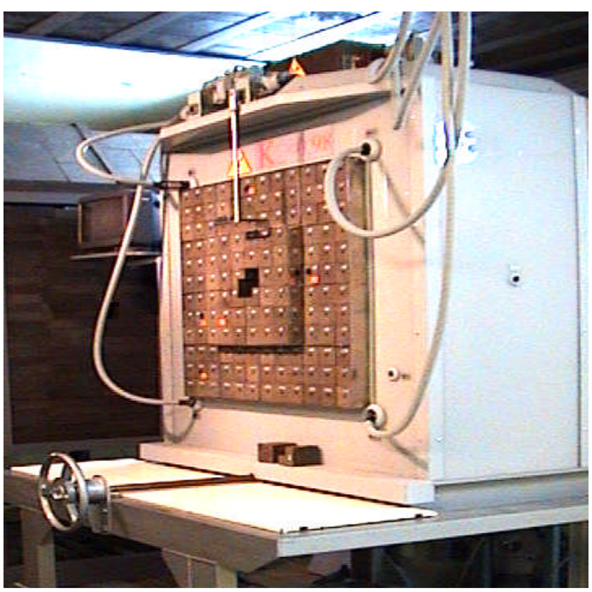

Fig.1. General view the YALINA-Booster subcritical assembly

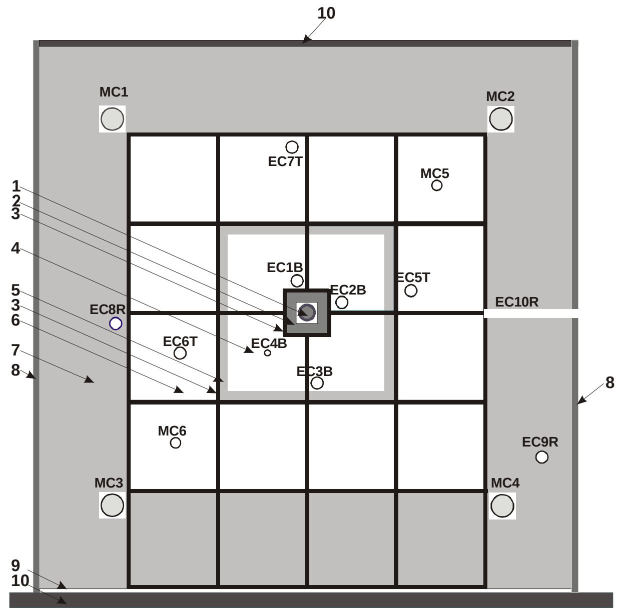

Fig. 2. X-Y cross section of the YALINA-Booster subcritical assembly
1 - deuteron beam tube, 2 - inner fast (booster) zone with $U_{met.}$ of 90% enrichment in lead, 3 - stainless steel frame, 4 - outer fast (booster) zone with UO_2 of 36% enrichment in lead, 5 - thermal neutron absorber, $U_{met.(nat.)}+B_4C$, in lead, 6 - thermal zone with UO_2 of 10% enrichment in polyethylene, 7 - graphite reflector, 8 - organic glass sheet, 9 - Cd layer, 10 - steel with low content of carbon, EC1B - EC4B experimental channels in booster zone, EC5T - EC7T experimental channels in thermal zone, MC1 - MC4 measurement channels in reflector, MC5 - MC6 measurement channels in thermal zone.

3. EXPERIMENTAL MEASUREMENTS

During the fuel loading process, the main requirement is to maintain the assembly at a subcriticality level less than 0.98. The reciprocal counting method of the neutron flux as a function of the number of fuel rods is utilized. This approach is easily achieved for homogeneous systems. In heterogeneous systems, additional safety precautions are considered.[4,5] In addition, the pulsed neutron source (PNS) area method was used to determine the subcriticality of the assembly.

3.A. Reciprocal Counting Method Measurements

The subcriticality of the assembly can not be measured directly but the neutron flux at any point within the assembly is proportional to the neutron multiplication. The neutron multiplication is determined experimentally by measuring the neutron flux within the assembly away from the source. The measurement is first made without any fuel and then it was repeated at the same location with the fuel present. The ratio of the two measurements is proportional to the neutron multiplication. The reciprocal of this ratio is then plotted against the number of fuel rods (or fuel mass). The plot extrapolation to zero gives the number of fuel rods (or fuel mass) required to achieve criticality. The measurements are repeated at another location to obtain another set of data, which should extrapolate to the same point. In YALINA-Booster subcritical assembly, the measurements have been performed in the experimental channels with different detectors at each step during the fuel loading process. The following measurement channels and detectors have been used:

- Channels MC1 and MC2 – Ionization chamber type KHK-56;
- Channels MC2 and MC3 – Corona 3He detector type CHM-18;
- Channels MC5 and MC6 – Proportional 3He detector type 12NH25/1F.

A ^{252}Cf neutron source with intensity of 2.56×10^{6} n/s was placed in central axial channel of the assembly during the fuel loading process. The measured values are shown in Fig. 3 for the different measurement channels. The extrapolation of the results shows that the assembly requires more than 1150 EK-10 fuel rods to reach criticality.

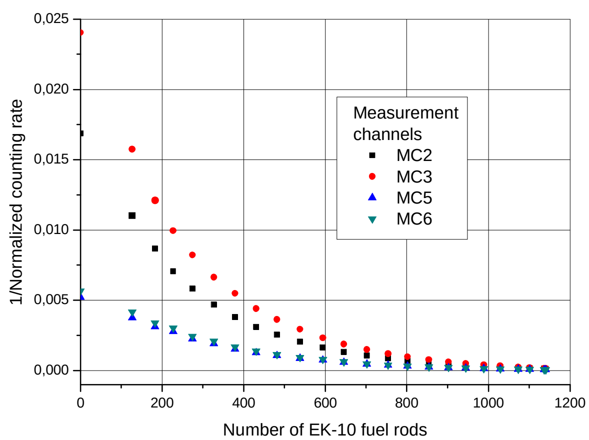

Fig.3. The reciprocal counting values as a function of the number of EK-10 fuel rods

3.B. PNS Area Method Results

The PNS area method assumes the similarity of the shape of delayed neutrons eigenfunction and the shape of the fundamental kinetic eigenfunction of prompt neutrons. This assumption holds for detectors located away from the boundaries of the fuel zone. The reactivity can be defined as follows:

$$-\rho(\$) = \frac{f \cdot A}{\alpha \cdot B}, \qquad (1)$$

where ρ is reactivity in dollars, f is frequency (s^{-1}), A is a constant obtained from fitting the detector response using equation 2, α is the slope of the prompt portion of the detector response curve yields the fundamental mode decay constant (s^{-1}), B is the steady state portion of the curve corresponding to the delayed neutrons of equation 2. PNS area method fit the detector response using the following function:

$$y = B + A \cdot \exp(-k \cdot x) \qquad (2)$$

The relative error of this method is estimated by the following equation:

$$\frac{\Delta\rho}{\rho} = \frac{1}{f \cdot \alpha}\sqrt{A^2 \cdot (\Delta f)^2 + f^2 \cdot (\Delta A)^2 + \left(\frac{f \cdot A}{\alpha}\right)^2 \cdot (\Delta\alpha)^2 + \left(\frac{f \cdot A}{B}\right)^2 \cdot (\Delta B)^2} \qquad (3)$$

The reactivity (in dollars) of equation (1) can be expressed by the ratio A_1/A_2, where A_1 is the area under the curve of the detector response corresponding to the prompt neutrons (the varying section of the curve), and A_2 is the area under the same curve corresponding to the delayed neutrons (the steady state portion of the curve).

The reactivity measurement results during the loading of the thermal zone of the YALINA-Booster have shown that the relative uncertainty of the reactivity estimate is about 1.5% calculated from equation 3. The decay constant (α) of the neutron flux density measured with the pulse neutron source method in experimental channels EC5T and EC6T of thermal zone is presented in Fig.4. The obtained results of the prompt neutron decay constant have been obtained by using the Levenberg-Marquardt method with selection of weighting method for a Chi-square minimization of the non linear curve fitting module.

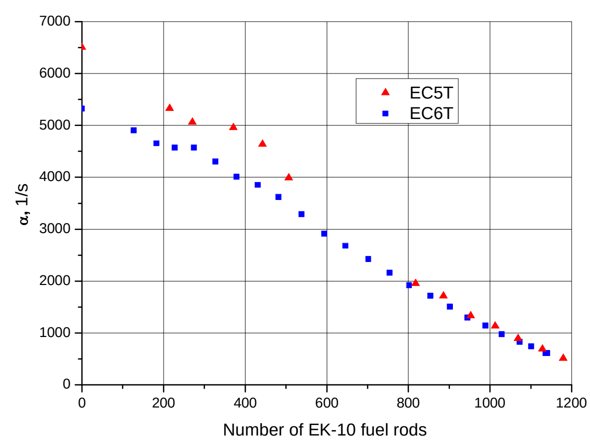

Fig.4. Prompt neutron flux decay constant (α) measured in the experimental channels EC5T and EC6T of the thermal zone using D-T neutrons in pulse mode

The fitting region has been chosen in such a way that the influence from the higher harmonics does not influence the results. In addition, the detector response due to the delayed neutrons should reach be a steady-state, which requires ignoring the initial pulses. The neutron source frequency is adjusted to get clear representation for the prompt and the delayed neutrons. The counting interval length varies with the assembly subcriticality level.

The reactivity of the YALINA-Booster assembly estimated by the PNS area method during the fuel loading process for different fuel arrangement using different detector positions is presented in Fig.5. As the number of fuel rods exceeds 860 corresponding to k_{eff} of ~0.92, the measured reactivity values for the square shape assembly with the detector located in the EC5T channel and the circular shape assembly with detector located in the EC6T channel are almost the same.

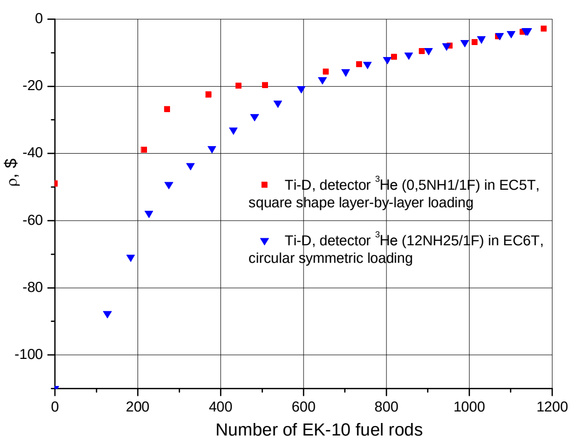

Fig.5. Reactivity versus number of EK-10 fuel rods with the PNS area method

4. CONCLUSION

In this paper, results obtained by reciprocal counting and PNS area methods during the YALINA-Booster loading process are presented. The measured reactivity results are given as a function of the number of EK-10 fuel rods loaded into thermal zone. For YALINA-Booster assembly, PNS area method measurements of the subcriticality level revealed the following characteristics:

- As the fuel loading of the assembly increases near the critical state, spatial effects become insignificant.
- During the fuel loading process, reactivity measurements by the PNS area method should be performed simultaneously through the whole assembly using multi-parameter Data Acquisition System. This approach help define the assembly configuration where the PNS method starts to give the reliable results. In addition, the neutron detectors should be positioned both in the fast and thermal zones of the assembly;
- The measured spatial distribution of the neutron flux density in the thermal zone is influenced by square shape of fast zone and it should be taken into consideration in planning future experiments.

ACKNOWLEDGMENTS

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