

THE PARTICIPATION OF IPEN IN THE IAEA COORDINATED RESEARCH PROJECTS ON ACCELERATOR DRIVEN SYSTEMS (ADS)

J.R.Maiorino, A. Santos, T. Carluccio, P. C. R. Rossi, A. Antunes, F. de Oliveira and S. M. Lee.

Instituto de Pesquisas Energéticas e Nucleares (IPEN / CNEN - SP)
Av. Professor Lineu Prestes 2242
05508-000 São Paulo, SP
maiorino@ipen.br

ABSTRACT

This paper describes the participation of the IPEN in the International Atomic Energy Agency (IAEA) Coordinated Research Projects (CRP) on i) Analytical and Experimental Benchmark Analysis on ADS and ii) Low Enriched Uranium Fuel Utilization in ADS. The first CRP has as specific objective to improve the present understanding of the coupling of an external neutron source [e.g. a spallation source in the case of the accelerator driven system (ADS)] with a multiplicative sub-critical core, and the second CRP, or collaborative work, the utilization of LEU in existing or planned ADS facilities. IPEN participate in both CRP through a Research Contract (13388), and although there are several benchmarks defined in both CRP, presently IPEN is participating in the activities related with Reactor Physics Benchmark of the YALINA BOOSTER facility in Belarus, in the Analytical and Numerical Benchmarking of Methods and Codes for ADS Kinetics, and in the ADS Target Calculations. Besides, since there are plans to introduce a compact neutron generator in a sub critical core of the IPEN-MB-01 facility, a benchmark of a simulation of such project has been proposed in the LEU-ADS CRP. The paper will review the CRPs, with details on the activities in which IPEN is participating.

1. INTRODUCTION

Given the interest in R&D in Accelerator Driven Systems [1] by several member states the International Atomic Energy Agency (IAEA) has initiated a Coordinated Research Project (CRP) on “Analytical and Experimental Benchmark Analyses of Accelerator Driven Systems [2].

The objective of this CRP is to improve the present understanding of the coupling of an external neutron source [e.g. a spallation source in the case of the accelerator driven system (ADS)] with a multiplicative sub-critical core,

The participants are performing computational and experimental benchmark analyses using integrated calculation schemes and simulation methods, and comparing with experimental results from zero power sub critical source driven system (e.g. YALINA Booster in Belarus, or targets irradiated by high energy. protons from available accelerators (SAD at JINR, Dubna). It is important to underline the common objective of these experimental facilities, which is to validate computational methods, obtain high energy nuclear data, characterize the performance of sub-critical assemblies driven by external sources [e.g., spallation, (D,D) or (D,T) neutron sources, and photon-neutron sources based on electron accelerators], and, last but not least, to develop and improve techniques for sub-criticality monitoring. Also

Analytical and Numerical Benchmarks, mainly in Kinetics, and analysis of projects on going are being considered.

Currently, 27 institutions in 18 Member States and two international organizations are actively participating in this CRP: CA Bariloche (Argentina), SCK•CEN (Belgium), IPEN (Brazil), Joint Institute of Power Engineering and Nuclear Research Sosny (Belarus), CIAE (China), CEA Cadarache and CNRS Paris (France), FZ Rossendorf and FZ Karlsruhe (Germany), BUTE (Hungary), Politecnico di Torino (Italy), JAEA (Japan), NRG (the Netherlands), PINSTECH (Pakistan), AGH-University of Science and Technology Krakow and Institute of Atomic Energy Otwock/Swierk (Poland), ITEP, RRC-KI and Moscow Physical Society (Russia), Universidad Politécnica de Madrid, Universidad del Pais Vasco / Euskal Herriko Unibertsitatea (UPV/EHU), and CIEMAT (Spain), Royal Institute of Technology Stockholm (Sweden), National Science Center “Kharkov Institute and Technology” (Ukraine), Argonne National Laboratory (USA), IAEA, and JINR (Dubna). Also given the concern of the RERTR, and the non proliferation police of the IAEA a cooperative work was established to study the feasibility to use Low Enriched Uranium in existing or planned facilities, under the umbrella of the main CRP and with support of DOE of the USA. After a Workshops held in Vienna [3], a cooperative work was establish among interested members state, to study the facilities described in 2

2. BENCHMARK DESCRIPTION

In a first stage of the CRP, the participants agreed to analyze the following benchmark problems based on experiments: (i) YALINA-Booster; (ii) spallation target parametric studies with experimental validation; (iii) spallation source efficiency and energy dependence; (iv) sub critical experiments; and (v) photonuclear based transmutation benchmarks. In addition, the CRP will address purely analytical benchmarks in two areas: (i) analytical and numerical benchmarking of methods and codes for ADS kinetics; and (ii) ADS concepts. ADS performance benchmark calculations will also be performed, and, if available, experimental backing will be considered.

In the cooperative work on the utilization of LEU in ADS the following operating or planned facilities: are being considered: (i) YALINA THERMAL, (ii) Reduced Enrichment studies of the YALINA BOOSTER facility, (iii) Kharkov Sub Critical Research Reactor driven by an electron accelerator (Ukraine), (iv) a feasibility study of a Sub critical core of the IPEN-MB-01 driven by a D-D or D-T neutron source , (v) The pre TRADE experiment(a D-D, D-T sub critical TRIGA Reactor in Casaccia, and the (vi)Serbia H5B Accelerator Sub Critical Research Facility using LEU TVR-S fuel in a lead matrix.

IPEN is participating in the main CRP, and also in collaborative work on the utilization of LEU in experimental ADS, however given the limitation of man power, we restricted, at least in the short range, to the following Benchmark exercises: i) YALINA BOOSTER, ii) Spallation Target studies with experimental validation, iii) analytical and numerical benchmark of methods and codes for ADS kinetics and codes, iv) target parametric studies of the H5B facility , and the feasibility study of a Sub critical core of the IPEN-MB-01 driven by a D-D or D-T neutron source. Although several papers at this conference will given results obtained up to today, here we wish describe shortly each of this Benchmark exercises.

2.1. YALINA BOOSTER

The sub-critical assembly YALINA-Booster has been assembled at the Joint Institute for Power and Nuclear Research Sosny (JIPNR) of the National Academy of Sciences of Belarus (the schematic set-up is shown in Fig. 1). It has a fast spectrum (“booster”) zone in the

center, surrounded by a thermal one. The sub-critical core is driven by an external deuterium (d,d) or tritium (d,t) neutron source. The “booster” zone is increasing (through fast fissions) the efficiency of the neutron source. Between the fast and the thermal zones, there is a “buffer” zone that consists of one layer of natural metallic uranium rods and one layer of boron carbide rods that allows for fast neutron leakage into the thermal zone, and at the same time reduces thermal neutron leakage into the fast zone. In the radial direction and axially, the sub-critical assembly is shielded by a graphite reflector and by a borated polyethylene reflector, respectively. The radial reflector and the backside of the thermal zone are covered by organic glass.

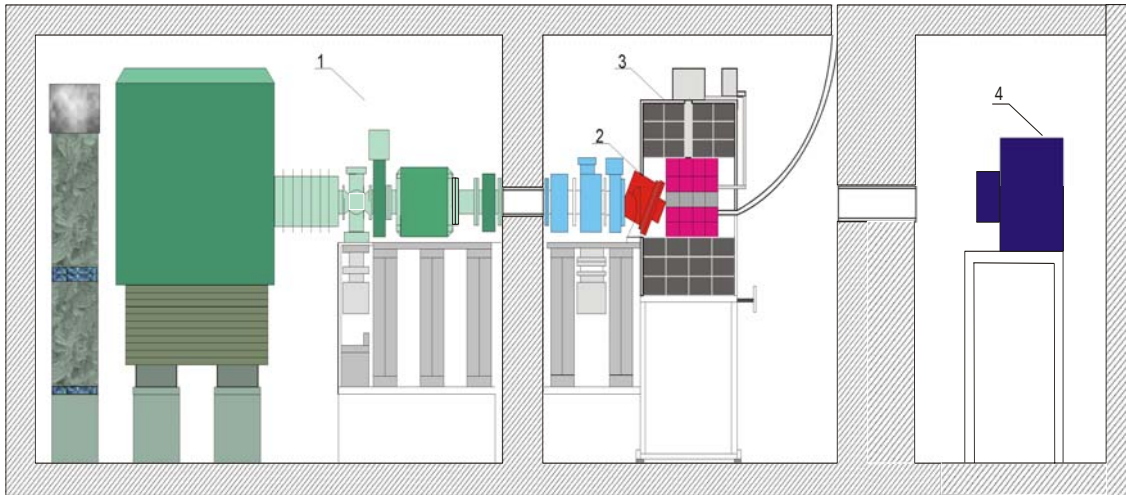


Figure 1: General set-up of the sub-critical facility YALINA: d-accelerator (1); neutron producing Ti-t (or Ti-d) target (2); sub-critical assembly (3), gamma-spectrometer (4)

The core of the YALINA-Booster sub-critical facility is a horizontally laid-out rectangular parallelepiped. Fig. 2 shows an X-Y cut (at $Z=0$) of the “booster” zone. The “booster” zone contains 36 lead subassemblies: 4 central ones, and 32 outer ones. The 4 central subassemblies contain 132 metallic uranium (90% ^{235}U enrichment) fuel pins, while $\frac{1}{4}$ of the volume of these central subassemblies is occupied by a central cavity (80x80x645 mm), which contains the lead target. The (d,d) or (d,t) neutron source can be located at different positions from the core centre along the axis of this cavity, allowing to perform, among others, to study the dependence of the efficiency of the external source from its location. Each of the remaining 32 outer lead subassemblies contains 25 stainless steel tubes arranged in a square 16 mm pitch lattice. 575 of these tubes are filled with uranium oxide fuel (36% ^{235}U enrichment). The two outer most rows are forming the “buffer” zone, consisting of one row (108 tubes) metallic natural uranium fuel rods, and one row (116 tubes) boron carbide rods. The “booster” zone is surrounded by the thermal zone consisting of 108 polyethylene subassemblies that provide a 20 mm pitch square lattice containing aluminum clad uranium oxide fuel (10% ^{235}U enrichment). In all, the YALINA-Booster sub-critical facility has nine axial (4 in the “booster” zone, 3 in the thermal zone, and 2 in the reflector zone), and one radial (in the reflector zone) experimental channel. Various sub-critical configurations are envisaged for the YALINA-Booster benchmark, differing in the number of 10% ^{235}U enriched fuel rods. In all configurations, the “booster” zone is fully loaded, and the (d,d) neutron source is used. For each configuration, the following calculations will be performed by the benchmark participants: (i) axial distributions of $^3\text{He}(n,p)$, $^{235}\text{U}(n,f)$, and $^{115}\text{In}(n,\gamma)$ reaction rates; (ii) radial $^{115}\text{In}(n,\gamma)$ reaction rate distribution; (iii) $^{197}\text{Au}(n,\gamma)$ and $^{55}\text{Mn}(n,\gamma)$

reaction rates in mid-plane positions in both the “booster” and in the thermal zone; (iv) neutron spectrum; (v) neutron flux in function of time; (vi) effective and source multiplication factors (k_{eff} and k_s), mean neutron generation time (Λ), and effective delayed neutron fraction (β_{eff}); (vii) feasibility of sub-critical experiments using low-enriched uranium.

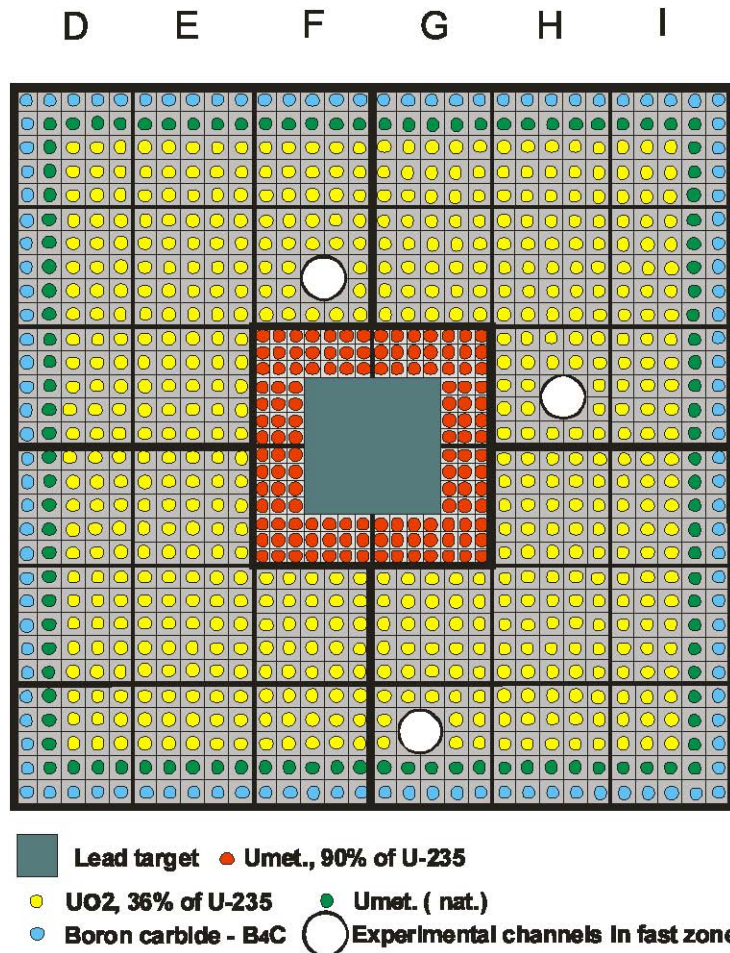


Figure 2: X-Y cross section (at Z=0) of the “booster” zone

2.2. Analytical and Numerical Benchmarking of Methods and Codes for ADS Kinetics

An analytical benchmark is constituted by a closed-form solution to some reference exemplary problem to be used for the verification and validation of numerical techniques and codes. The solution is to be obtained by a direct solution of the model equations for simplified configurations, allowing the application of analytical tools, although retaining the main significant physical features of the problems to which numerical codes should be applied. Therefore, no discretization is used, and full error control is guaranteed. Analytical benchmarks allow carrying out the following important steps in numerical code validation: (i) to verify that the equations are adequately solved; (ii) to separate model and numerically induced effects; (iii) to fully comprehend the physical phenomena involved; and (iv) to determine the limitations of approximate models (e.g. diffusion vs. transport, anisotropy effects).

On the other hand, a numerical benchmark involves the direct comparison among different codes in order to achieve the following objectives: (i) assess the accuracy and efficiency of the algorithms; (ii) establish the code performance; and (iii) highlight possible shortcomings of numerical procedures.

The activities of this CRP task will allow to identify some significant exercises in the field of the dynamic problems related to source-driven systems, and to produce a collection of exact analytical solutions whenever possible, or highly accurate numerical solutions with a reliable error control, in order to obtain a deep physical insight into the problems considered and to establish validation references for numerical codes.

In cooperation of Politecnico de Torino, we already solved a 3 region slab resembling the Yalina booster by the expansion method and the results were presented at the M&C conference [4]. Also at this conference a paper containing the analytical solution of time dependent diffusion equation with precursors is presented [5].

2.3. Target Studies

Although there plans to define several benchmarks related with targets to validate codes and nuclear models of the spallation reaction, presently we are working with a Benchmark on Computer Simulation of radioactive nuclides production n rate and Heat Generation Rate in a lead target exposed to 660 MeV protons., defined by the participants from Poland. The benchmark model is based on the earlier experiment done within the projects MUSE and SAD, in the Joint Institute of Nuclear Research in Dubna (Russia). In the experiment absolute activities of several long-lived radionuclide's, generated in lead target during its irradiation with 660 MeV proton beam, were determined. Thus, the benchmark is oriented to compare simulation predictions, based on different available codes and physical models, with the experimental data. A scheme of the target proposed to be simulated by the CRP participants is illustrated in figure 3.

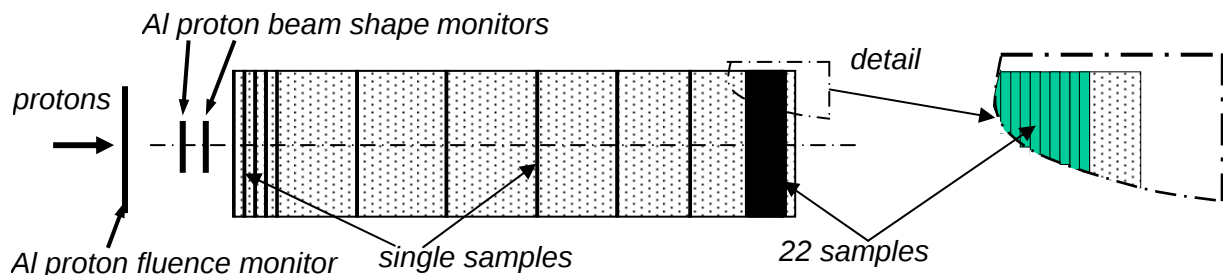


Figure 3: Scheme of the thick target to be simulated

Another benchmark we are involved is the Serbia H5B Accelerator Sub Critical Research Facility with low enriched TVR-S fuel in lead matrix. The Benchmark Calculation for target of this facility is constituted of a cylindrical target of Lead, Uranium, Thorium, Bismuth, Lithium, Beryllium, Tungsten, and Pb-Bi alloy. The beams considered are 73 MeV protons, and 67 MeV deuteron. Preliminary results for these targets are presented at this conference [6]

2.4. Study of a Sub critical core of the IPEN-MB-01 driven by a D-D or D-T neutron source

The Brazilian Facility IPEN-MB-01 is a Zero Power Reactor (100 watts), light water tank type, consisting of a 28x 26 rectangular array of UO₂ fuel pins, 4.3 w/o, with a clad of SS-

304.. These critical lattices consist of nearly square, uniform lattices of stainless-steel-clad cylindrical fuel rods immersed in light water. The pitch of the rods is 15.0 mm, is close to the optimal pitch (maximum k_{∞}).

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.

. 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 [7].

In the framework of the collaborative work to use LEU in experimental ADS, we proposed the feasibility studies of a sub critical core without control rods driven by a neutron source (D-D, D-T), as illustrated in figure 4. The participants will perform calculation of static parameters (k -effective, k -source, flux distribution, neutron spectra), as well as dynamic parameters, and the results will be compared in the next RCM(Research Coordinated Meeting), planned to be held in November in Rome .Also a paper presented at this conference will show preliminary results obtained by MCNP and TORT code[8].

3. CONCLUSIONS

The paper outlines background, scope and major objectives of the IAEA Coordinated Research Project on “Analytical and Experimental Benchmark Analyses for Accelerator Driven Systems”, and describes the various benchmark exercises, mainly those that IPEN is participating. The Coordinated Research Project aims at integrating some of the planned experimental demonstration projects of the coupling at power between a sub-critical core and an external neutron source and thus at strengthening the validation base for ADS computational methods. For IPEN the participation in the CRP will allow to implement and qualify its Reactor Physics Calculation Methods, both deterministic and Monte Carlo

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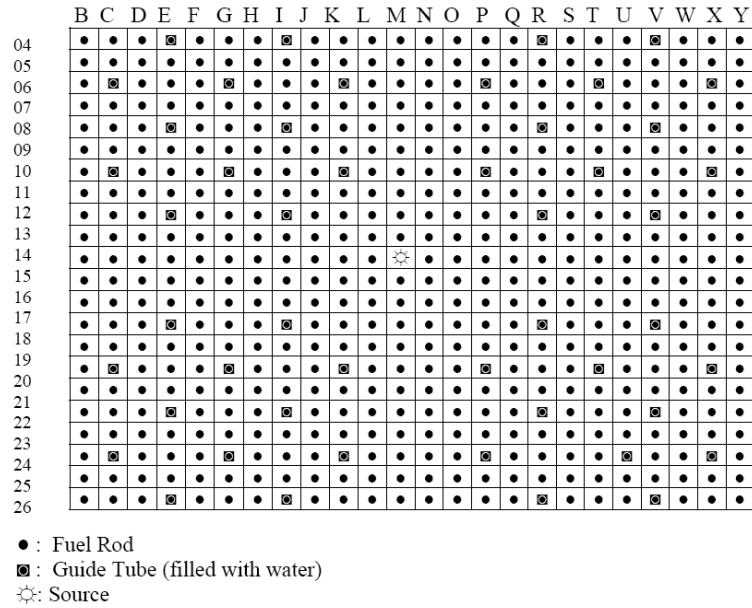


Figure 4: Sub critical core to be considered in the calculation

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