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The Utilization of a Cyclotron CV-28 in Basic and Applied Nuclear Research and in an Experimental Accelerator Driven System Zero Power Lead Sub Critical Facility

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This paper describes the IPEN Cyclotron CV-28, and its utilization in basic and applied physics and to drive a zero power lead Accelerator Driven System (ADS), as a milestone in a road map for a program or network on the utilization of accelerators. Preliminary results for a conceptual lead sub critical cubic matrix with square or hexagonal metallic U pins driven by a proton beam (24 MeV; 50 μ A) are shown. These results demonstrate the feasibility to use the CV-28 to drive the zero power ADS.

1 Introduction

As previously reported the utilization of accelerators in sub critical systems for energy generation and mainly for nuclear waste transmutation, deserves an international attention in R&D programs. Also a proposal of a national program or net work of research on the utilization of accelerators in basic and applied nuclear research, products and services and an experimental accelerator driven system (ADS) was proposed [1]. To achieve the final goal, that is to have a medium size accelerator facility that could be used in the fields described above, a road map should be followed. One of the milestones of this road map is to have a zero power sub critical facility driven by accelerator, which would allow to initiate R&D in the experimental physics of ADS and to participate in the international effort being conducted to provide data on such innovative nuclear system. This paper will describe how the IPEN CV-28 cyclotron could be used in the scenario described above.

2 The Cyclotron CV-28

2.1 Description

The cyclotron model CV-28, manufactured by The Cyclotron Corporation USA, is a compact, isochronous, multi-purpose radiation source where protons, deuterons, ³He⁺⁺ and alpha particles can be accelerated with variable energy up to 24, 14, 36 and 28 MeV respectively. It is a versatile machine and can be used in research and development in many fields such as radioisotope production, excitation functions studies, nuclear reactions, materials science and others. Although it has seven external beam lines available, only three are operational and are located inside the cyclotron vault. The nominal characteristics are shown in Table 1.

TABLE 1. Nominal characteristics of the cyclotron CV-28.

Particle	Energy (MeV)	I_{ext} (μ A)	I_{int} (μ A)
H ⁺	2-24	40-60	200
² H ⁺	4-14	50-100	300
³ He ⁺⁺	6-36	5-50	135
He ⁺⁺	8-28	6-40	90

Reference 2 contains a detailed description of the CV-28 cyclotron and Fig. 1 illustrates the CV-28 Vault.

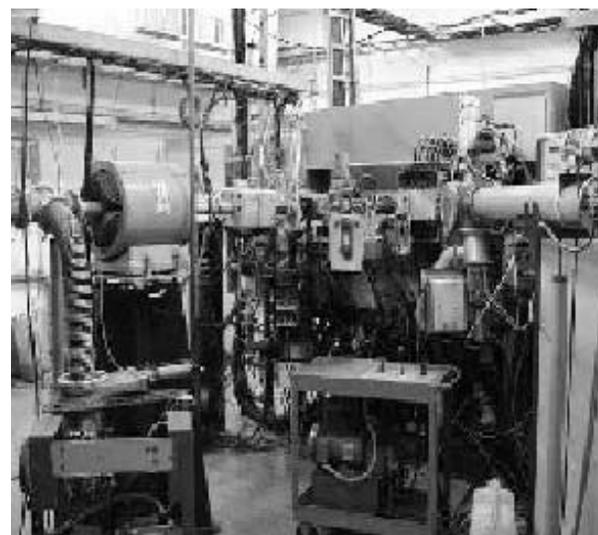


Figure 1. The Cyclotron CV-28 Cave.

TABLE II. Zero Power ADS in the world[6].

Facility Place	Accelerator Source	Sub Critical	Status Utilization
FEAT CERN Geneve Switzerland	Proton Synchrotron	Natural. Metal U Hex. pin water- TH (k=0.92)	Validation of MC codes, ADS Gain
YALINA Misk Belarus	Neutron Gener- ator (D-T) 10^{12} n/s	10w/o UO ₂ pin in a CH ₂ C(TH) k < 0.98	Operational and Reactiv- ity Spectra Dy- namics Experiments
MAZURCA MUSE CEA - Cadarache - France	Deuteron GENEPI Acc.(D-T) 10^9 n/s or ²⁵² Cf	Several Config- uration - Fast, sodium, Pb- Bi;U-Pu fuel	Operational Eu- ropean Bench- mark, Kinetics and dynamics
LA-0 NG-2 Czech Republic	Cyclotron U-120M Be-Target	Molten Fluor- ide Salt Fuel	Planned, Design stage
India	400 KV neutron D-T Generator	Not defined	Planned
TEF-P JAERI	Proton Beam(600 MeV) Spallation Pb-Bi 10^{12} n/s	Fast Split Table, 100W	Planned, design transmutation, Control, reactor physics

2.2 Utilization of CV-28

The use of cyclotron beam covers a wide range of applications in Basic and Applied Physics as described in reference 3, and in short they are: Charged Particle Activation Analysis (CPAA), Thin Layer Activation (TLA), Neutron Radiography, Rutherford Back Scattering (RBS), Elastic Recoil Detection Analysis (ERDA), Particle Induced X ray Emission (PIXE), Radiation Damage and Basic Research. Of course, there are many other uses, such as proton therapy, ion implantation, micro filters etc. Moreover, since the CV-28 has only three available beams, the scientific community has to choose among the several possibilities which one is more attractive. Without being conclusive looks like the CV-28 could be used in the following utilization: (1) to drive a zero power ADS, as will be discussed bellow, (2) Radiation Damage and (3) TLA.

3 The Zero Power ADS

Power and Waste Burner ADS are still on the stage of development, and although several concepts are underway [4,5,6,7], none of them have been built. R&D activities are being developed in several fields, such as in Reactor Physics, Nuclear Data, Target, Fuels, Thermal Hydraulics, Spallation Physics and Transmutation etc. For Reactor Physics and Nuclear Data, experimental facilities operating at zero power (few watts) are in operation or being planned, with the purpose to provide experimental benchmark on calcula-

tion methodology and nuclear data. Table 2 summarizes the main facilities in operation or on planning.

Given the conceptual modified fast energy ADS under study [8,9], it is proposed a solid lead zero power ADS, using U/Th fuel, and using as neutron source proton or deuterium from the CV-28 in a Be or Li target, or 14 MeV neutron from a D-T reaction from a 400 kV existing Van de Graff. Here we will describe the feasibility study made by using the CV-28. The proposed conceptual sub critical, is illustrated in Fig. 2 and in short it consist of lead blocks supported by a SS structure, containing holes in which the fuel elements are inserted. Given the low power, it is cooled by air natural convection.

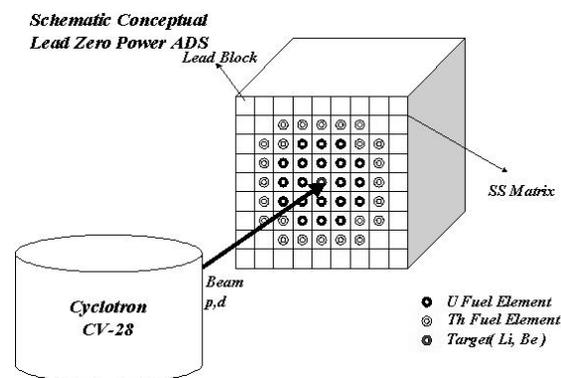


Figure 2. Schematic Conceptual Lead Zero Power ADS, driven by CV-28.

3.1 Neutron Source Term

The external neutron source to drive the Zero Power ADS, using CV-28, could be induced by nuclear reaction of protons or deuterons with targets of Beryllium or Lithium to produce fast neutrons. Experimental results of the neutron yield, angular and spectral distribution were obtained by Lone [10]. Fig. 3 illustrates the experimental results for the neutron source intensity.

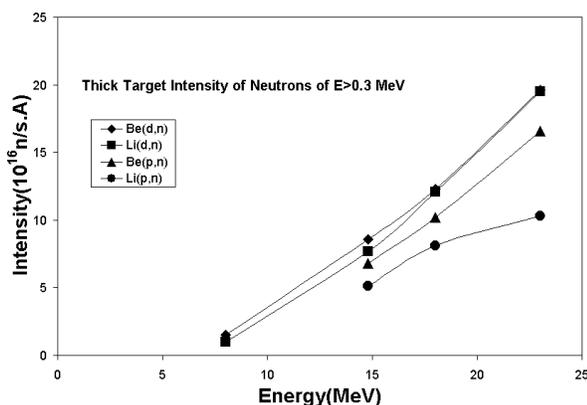


Figure 3. Neutron Source Intensity.

From these data, for thick Be target, the CV-28 ($E_p = 24$ MeV, $I = 50 \mu A$), can provide neutrons with intensities 10^{11} - 10^{12} n/s, and average energy 5.1 MeV ($E_n = 1.14 \times E_p^{1.13}$). Also the Lone experimental results were reproduced by LAHET [11], and the results obtained were in good agreement. Therefore in the simulations, the source term was calculated by LAHET.

3.2 Calculation Methodology

The methodology employed in this work is shown in Fig. 4. It is based in the LAHET [11] and MCNP-4C [12] code systems. LAHET is the LANL version of the HETC Monte Carlo for the transport of protons. Its geometric transport capability is that of LANL's continuous energy neutron-photon Monte Carlo code MCNP-4C. The calculation methodology is made of two parts. In the first part LAHET performs the transport of protons and the subsequent characterization of the neutron and gamma sources arising from the nuclear reactions in the target. For this purpose, LAHET employs a Monte Carlo approach for the transport of protons through the lead target. The sources are written in special files denominated as NEUTP for neutrons and GAMTP for gamma for subsequent MCNP-4C utilization. Beyond that, LAHET has also the capability to calculate the energy deposited in the target as well as the reaction products. The second part of the calculation methodology concerns the k_{eff} determination and the transport of neutrons and gamma through the fuel core and its surroundings. This task is accomplished by the continuous energy neutron-photon Monte Carlo code MCNP-4C. The nuclear data needed for MCNP-4C are generated by NJOY [13] accessing the ENDF/B-VI nuclear data file.

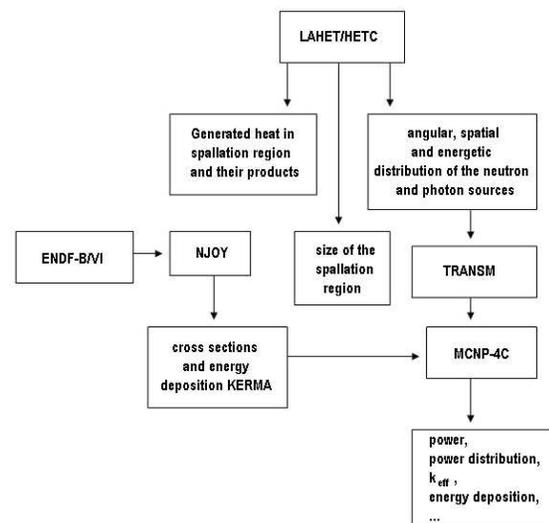


Figure 4. The methodology employed in this work is based in LAHET and MCNP-4C code systems.

3.3 Cases Simulated and Results

There are some options that were taken into account. Basically there are two ways to define the fuel pin distribution: square lattice and hexagonal lattice. In the first one two configurations were designed, where the basic difference is the fuel pin diameter. The diameter varies from 2.5 cm to 10.0 cm, and the reason is purely due to manufacturing capability at IPEN. The core containing fuels with diameter of 10 cm, has a total amount of fuel about 7,000 kg with 48 fuel pins (case 1). In the second case (2.5 cm diameter) the total amount of fuel are 10,000 kg and 1080 fuel pins. In the hexagonal geometry, the fuel pin diameter is 1.138 cm and the amount of fuel is 4,600 Kg and 5490 fuel pins (case 3). The first idea was to use natural Uranium, but due to the restricted space that is available ($1 m^3$), the multiplication factor obtained for this configuration was too small (~ 0.36), too far from the desired value 0.95. The adopted solution was to use enriched fuel. The ideal percentage obtained to each configuration is shown in Table 3. The most suitable configuration so far is the case 2 shown in Fig. 5.

TABLE III. Results

Cases	k_{eff}	Mass (kg)	Power (W)
case 1	0.95	7,000	0.05
case 2	0.96	10,000	150
case 3	0.94	4,600	0.0

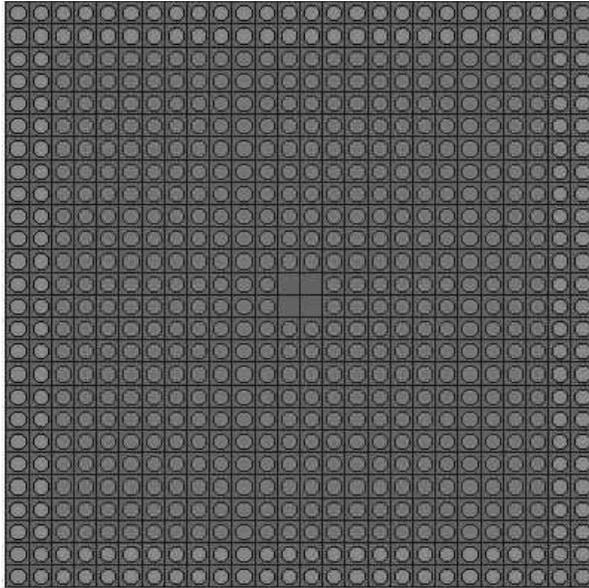


Figure 5. Case 2. Square configuration core: fuel pin diam. = 2.5 cm, pitch = 3 cm, enrichment = 8.5% .

4 Conclusions

The CV-28 is a suitable accelerator to be used in Basic and Applied Physics as well as to drive a zero power ADS. Its utilization would allow that the proposed net work of R&D be initiated toward in a final goal that is to have a new medium size accelerator to be utilized in R&D, Products, Services and a power experimental ADS. Additional studies needs to be made to evaluate the feasibility to operate the CV-28 in the present building, or to construct a new building or cave. The preliminary results shows that it is feasible to drive a lead zero power sub critical of $\sim 1 \text{ m}^3$, with ~ 100 watts, metallic uranium ($\sim 9\text{w/o}$ enriched), $k_{eff}=0.96$, using a proton beam (24MeV, $50 \mu\text{A}$) into a Be target (10^{11} - 10^{12} n/s) using CV-28. Additional calculations need to be made to refine the sub critical, such as pitch (square or hexagonal), enrichment, etc.

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