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Nuclear Instruments and Methods in Physics Research A 562 (2006) 883–886

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

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The Subcritical Assembly in Dubna (SAD)—Part I: Coupling all major components of an Accelerator Driven System (ADS)

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Available online 20 March 2006

Abstract

A demonstration facility for Accelerator Driven Systems has been proposed to be constructed at the Joint Institute of Nuclear Research in Dubna. The Subcritical Assembly in Dubna project proposes to couple an existing proton accelerator of 660 MeV and 1 μA current with a specially designed U-Pu MOX subcritical core. Project objectives, technical description and current status of the project are presented in this paper.

PACS: 28.50.Dr; 28.50.Qd; 28.41; 28.52

Keywords: Accelerator driven system; Subcritical reactors; Subcritical assembly in Dubna (SAD); Transmutation

1. Introduction

The construction of sizeable accelerator-driven systems (ADS) being able to transmute kilograms of transuranic elements should be preceded by a smaller experimental facility being able to proof problem-free operation of a subcritical core coupled through a spallation target with a proton accelerator [1]. The most important issues to be addressed are:

- ensuring operational safety of subcritical systems implying:
  - reliable control of the ADS power,
  - reliable monitoring of the subcriticality keff,
- measurement of the contribution of the high-energy part ($E > 10$ MeV) of the neutron spectrum, being particularly important for the design of radiation protection,
- engineering of the coupling of an accelerator with a subcritical reactor system.

Experimental ADS with thermal power in the range of 20–30 kW, as proposed in the Subcritical Assembly in Dubna (SAD) project, can properly address these problems and can demonstrate in practice feasibility of the accelerator–subcritical core coupling.

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0168-9002/$ - see front matter
doi:10.1016/j.nima.2006.02.175

Joint Institute of Nuclear Research in Dubna is a unique centre with broad competence both in accelerators and in subcritical systems, with experimental and theoretical research activities in this field conducted since the middle of the 1950s under the scientific label *electronuclear* research [2,3]. Neutron yields and spectra in lead and uranium targets have been measured, as well as neutron cross-sections for a number of isotopes, important for the estimation of the efficiency of various modes of transmutation [4–6]. For the analysis of the *electronuclear* systems properties, mathematical models with appropriate databases and software have been developed [7].

2. Basic parameters of SAD

One of the important arguments to start the SAD project in Dubna was existence of the proton accelerator "Phasotron" [8] with its predetermined characteristics. Subcritical core being designed for SAD facility has been based on the regular Russian MOX fuel elements of the BN-600 reactor type [9]. The proton beam with current of maximum value 3.2 μA impinging on a spallation target determines together with k_{eff} of a subcritical core, thermal power of the SAD installation.

The basic data of the SAD are listed in the Tables 1 and 2.

Table 1
SAD installation basic data

Parameter	Value
Thermal power	up to 30 kW
Proton energy	660 MeV
Beam power	up to 1 kW
Proton beam/target orientation	Vertical
Fuel elements orientation	Vertical
Criticality coefficient	$k_{eff} \approx 0.95$
Fuel—see Table 2 for details on composition	MOX, $UO_2 + PuO_2$
Cladding tubes max. temperature	400 °C
Spallation target	Replaceable: Pb, W
Reflector	Pb
Coolant	Air

Table 2
Basic features of the SAD core fuel

Parameter	Value
Fuel composition	$(UO_2 + PuO_2)$
Plutonium dioxide content in the fuel, %(mass)	up to 30
^{239}Pu content in Pu %(mass), not less than (accuracy not worse than 10^{-4} for basic isotopes)	95
Fuel density (g/cm^3)	10.4 ±0.2
Fuel pellet diameter (mm)	5.95

3. Subcritical assembly

The sub critical blanket of SAD (Fig. 1) is placed within a biological shielding, which is made of heavy concrete and placed in radial and top directions from the core (AC). Pipes are foreseen in the shielding blocks to provide the allocation of the cooling loops for the target, the core, the experimental channels (EC) (vertical and horizontal), the power control channels, the proton guide, etc. The upper part of the biological shielding will provide access to the blanket and to the EC during fuel loading/reloading operations and to experiments with detectors and samples. The SAD core consists of 141 fuel assemblies; each assembly by itself combines 18 fuel pins, separated by wire spacers, and welded onto the cladding tube in helical manner (Fig. 2). The fuel assembly does not have sidewalls, but only lower and top frames where the FE are fixed. A central supporting rod made of stainless steel achieves the integrity. The low specific energy release in the system allows the usage of air-cooling, both for the target and for the core.

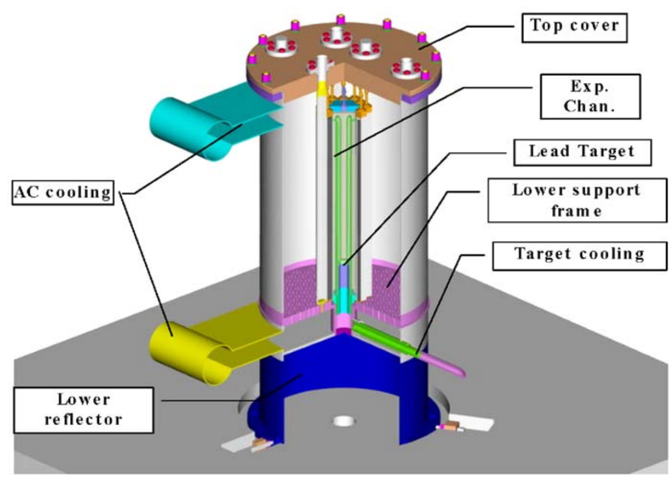

Fig. 1. SAD core general view, fuel assemblies and lead reflector not shown.

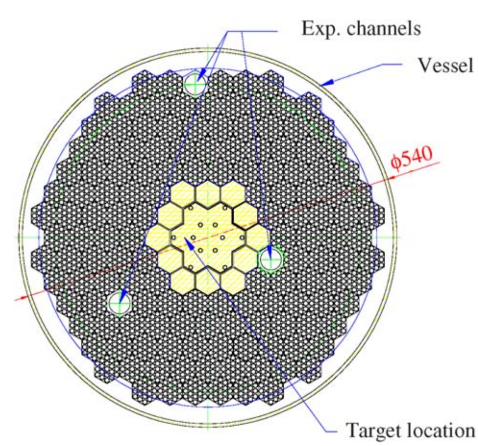

Fig. 2. Horizontal cross-section of the SAD core: 141 fuel assemblies × 18 fuel elements, 395 kg of UO_2–PuO_2 MOX fuel. 29.5 wt% of PuO_2.

The lead target assembly consists of a set of hexagonal lead prisms with air-cooling of the central 7 prisms (Fig. 3). Materials other than lead and other dimensions will be used for the target in the course of the SAD experimental program.

The active core is surrounded by a lead reflector of 60 cm thickness in radial direction and of 20 cm in axial direction at the top and at the bottom. The lead density is 11.15 g/cm^3. A B_4C layer of 3 cm thickness to reduce the number of low-energy neutrons in the concrete and shorten neutron lifetime in core is located between the lead reflector and the concrete shielding in radial direction.

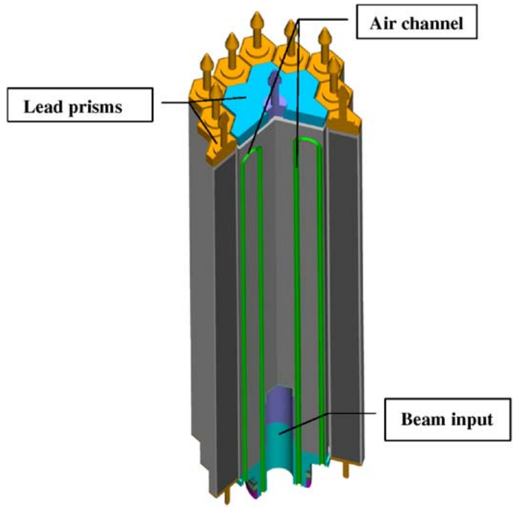

Fig. 3. Lead target with aircooling of central prisms.

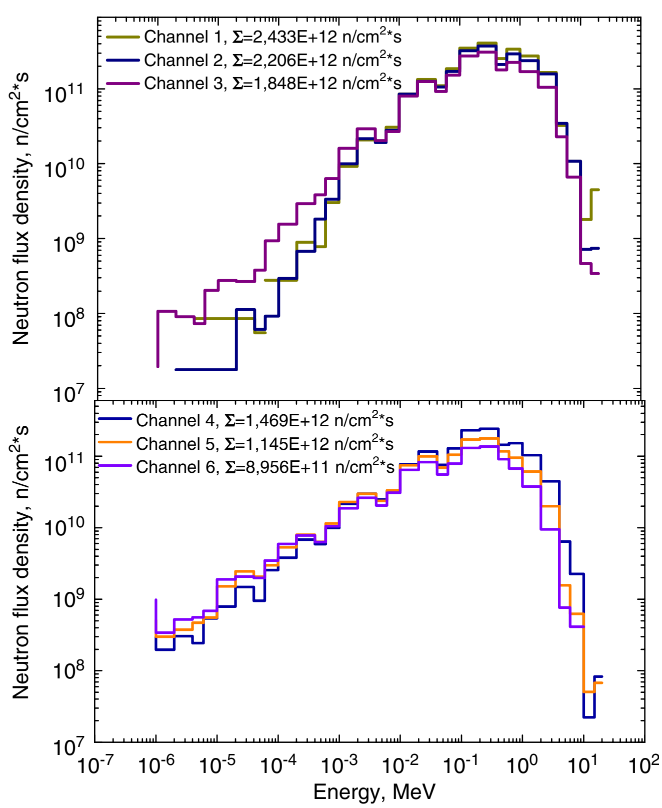

Fig. 4. Neutron spectra in the centers of vertical experimental channels 1–6.

The SAD facility will be equipped with EC and actuators, which will allow to place detectors and isotopic samples in different parts of the installation and to extract them after irradiation. Three vertical EC are located in the central part of subcritical assembly, substituting three fuel assemblies. One channel is in the vicinity of spallation target (EC1), next one in the middle of the core (EC 2) and the third one on the periphery of the core close to the Pb reflector (EC 3). Inner diameter of the channels 1–3 is equal to 33 mm. Another three vertical EC with inner diameter 60 mm are situated in Pb reflector.

The last vertical EC has diameter 45 mm and is placed in the top lead reflector on the beam axis.

Two horizontal ECs with diameter 100 mm are located in the lower and side lead reflectors.

On the basis of the data listed Above, preliminary neutron spectra in EC were calculated with MCNP [10] and MCNPX [11]. The results for neutron spectra calculations for 3 vertical channels in the fuel part of the core (1–3) and for 3 vertical channels in the side reflector (4–6) are shown in Fig. 4.

4. Accelerator and beam transport line

The PHASOTRON accelerator has 10 beam channels, used in various experiments. The normal beam losses at transition through the longest beam lines do not exceed 5%.

The beam transfer from horizontal into a vertical plane, entering from the bottom of the core, will be realised using two strong bending magnets which have to be designed and constructed (see Fig. 5).

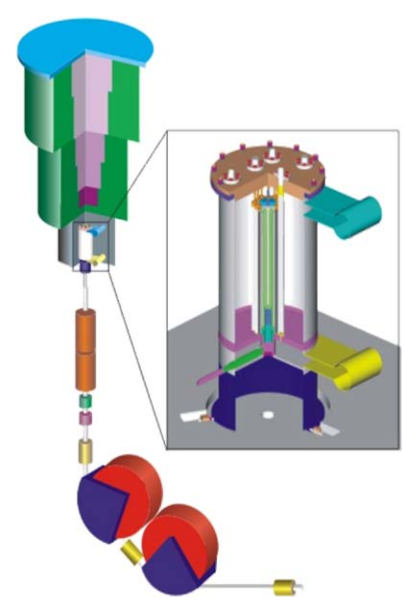

Fig. 5. A scheme of vertical injection of the proton beam into SAD-core.

The total number of magnetic elements in the beam line is about 40 including diagnostic elements and correction magnets. Beam current and spatial distribution will be monitored at different places along beam line using inductive sensors, ionization chambers and profilemeters. Beam current will be measured with high precision giving possibility for precise experimental monitoring of the core power to beam current ratio.

5. Status of the SAD project

The technical design of the SAD facility has been completed, the safety analysis report is under preparation, the technology of fuel pellet fabrication has been adopted and the experimental batch of fuel pellets has been manufactured.

6. Conclusion

The SAD project is in principle ready for licensing and realization. If no unexpected troubles appear the first proton can be shot on the spallation target in 4 years from now.

Research program and supporting experiments which are being conducted are described in a separate paper [12].

Acknowledgements

The SAD project is supported by the International Science and Technology Centre (Project #2267) and is conducted in a close collaboration with the European partners: Kungliga Tekniska Högskolan, Stockholm, CEA—Cadarache, FZK—Karlsruhe and CIEMAT—Madrid.

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