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The Subcritical Assembly in Dubna (SAD)—Part II: Research program for ADS-demo experiment

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Abstract

Subcritical Assembly in Dubna (SAD), a project funded by the International Science and Technology Centre, driven in collaboration with many European partners, may become the first Accelerator Driven Subcritical experiment coupling an existing proton accelerator of 660 MeV with a compact MQX-fuelled subcritical core. The main objective of the SAD experiment is to study physics of Accelerator Driven System ranging from a very deep subcriticality up to k_{eff} of 0.98. All experiences with subcriticality monitoring from previous subcritical experiments like MUSE, Yalina and IBR-30 booster mode will be verified in order to select the most reliable subcriticality monitoring technique. Particular attention will be given to validation of the core power–beam current relation. Moreover, some studies have been done to assess possibility of power upgrade for SAD.

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1. Introduction

The Subcritical Assembly in Dubna (SAD) may become the first Accelerator-Driven System (ADS) coupling an existing 660 MeV proton accelerator at the Joint Institute for Nuclear Research (JINR) in Dubna with a specially designed compact MOX-fuelled subcritical core.

SAD is today in an advanced design stage, in parallel with manufacturing of the first fuel pellets and conducting many supporting experiments. The design of the SAD is based on the core with a nominal power up to 30 kW, multiplication coefficient $k_{eff} = 0.95$ and accelerator beam power of 1 kW. Details of SAD design are presented in a separate paper [1].

2. Key parameters of SAD and supporting experiments

Many simulations using MCNPX [2] and LAHET [3] codes have been performed in order to choose optimal parameters for SAD [4–6]. Different combinations of the target, fuel and reflector materials have been considered. In particular thermal power the subcritical core driven with 1 kW proton beam has been studied as a function of k_{eff}, as presented in Fig. 1 [7].

We can find from Fig. 1 that at an average power gain—defined as a ratio of the power generated in the core to the proton beam power—$G = 30$ for $k_{eff} = 0.952$ and $G = 50$ for $k_{eff} = 0.972$.

Fig. 2 shows the neutron flux in experimental channel per 1 kW proton beam as a function of k_{eff}.

Maximum neutron flux in the experimental channel near the target reaches $2.26 \times 10^{12}\,\mathrm{cm^{-2}\,s^{-1}}$, for $k_{eff} = 0.952$ and $3.55 \times 10^{12}\,\mathrm{cm^{-2}\,s^{-1}}$ for $k_{eff} = 0.972$.

2.1. Heat generation and neutron flux in the target and experimental channels for different target materials and different position of the target in the subcritical assembly

Particular attention in SAD research program will be given to validation of the core power/beam current

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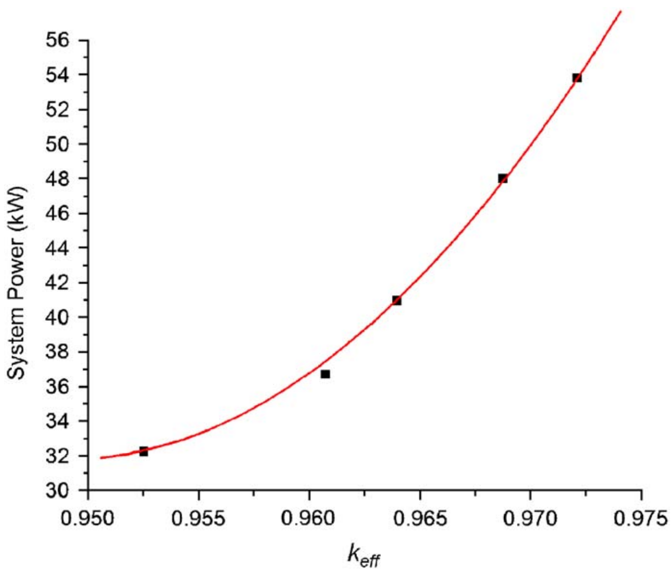

Fig. 1. SAD power as function of k_{eff} for 1 kW proton beam power.

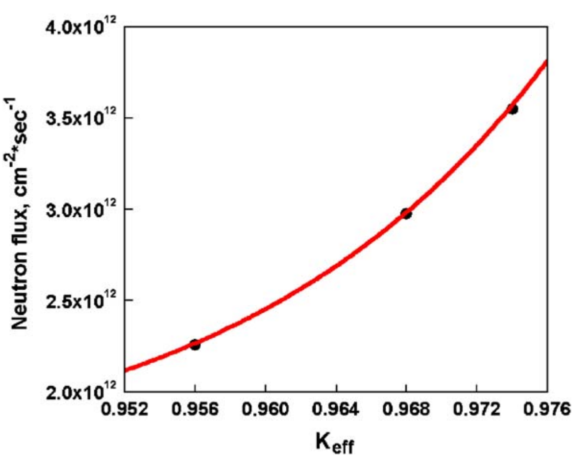

Fig. 2. Dependence of the neutron flux in the experimental channel on k_{eff}.

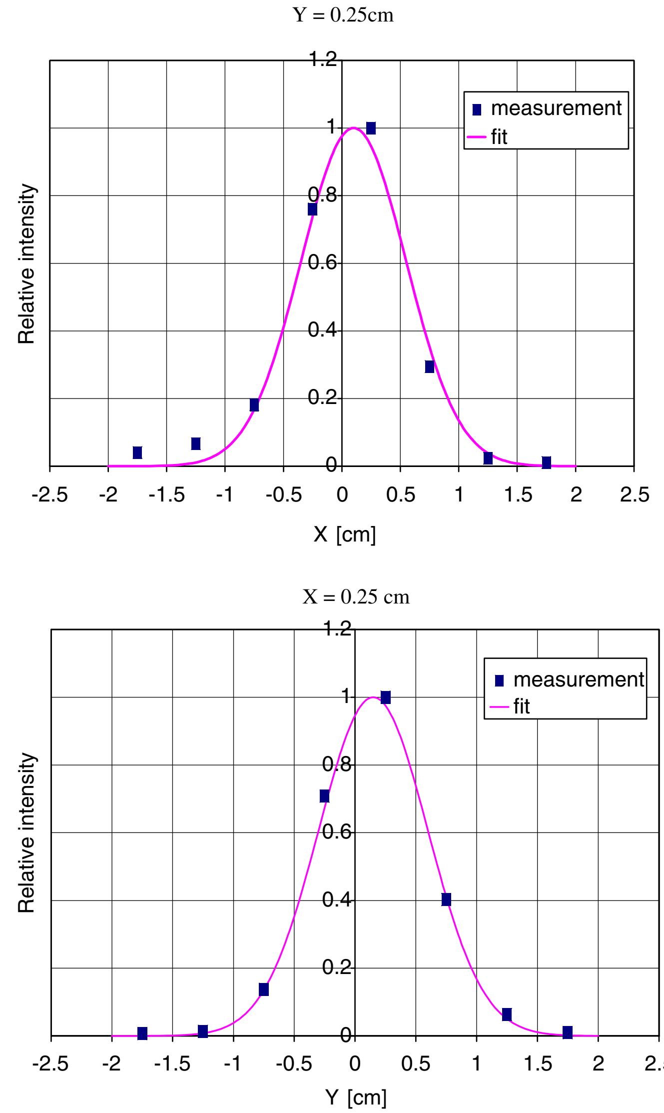

Fig. 3. Average proton beam profile at different X, Y cross-sections.

relationship as the main tool of monitoring subcriticality of this facility.

Beam current and shape will be monitored at different locations along beam line using inductive sensors, ionization chambers and profilemeters. Beam profile will be measured with high precision. Al activation detectors and matrix of thermoluminescent detectors, and profilometer will be used based on the existing experiences from accelerator operation.

The shape of the measured average proton beam profile is presented on Fig. 3 [8].

Power level of SAD will be monitored in two dedicated channels with 3 neutron sensors (high-sensitivity fission chamber, low-sensitivity fission chamber; boron current chamber). Additional neutron detectors may also be installed in SAD experimental channels. SAD has been designed from the very beginning to be a high-precision validation test-bed for ADS simulation codes. Each fuel element, a weapon grade Pu-MOX, will have its own certificate with a precise fuel isotopic content. Constructional materials also will be certified. It will give a unique possibility for precise modelling of this subcritical assembly and code benchmarking/validation activities.

To measure spatial and energy characteristics of the neutron field inside the subcritical assembly, the target and the core will be instrumented with threshold activation detectors (foils). To investigate high energy part of the neutron spectrum, absolute reaction rates will be determined for foils of ^{12}C, ^{27}Al, ^{59}Co, ^{63}Cu, ^{115}In, ^{197}Au, ^{209}Bi.

A multicomponent alloy $^{55}\mathrm{Mn} + {}^{63}\mathrm{Cu} + {}^{197}\mathrm{Au} + {}^{176}\mathrm{Lu}$ will be also used for measurements (n,γ) reaction rates in thermal and resonance energy region (up to 1 MeV).

The following spectral indices will be measured using ^{235}U, ^{239}Pu and ^{238}U:

- ^{235}U(n,f)/^{238}U(n,γ),

- ^{239}Pu(n,f)/^{235}U(n,f),
- ^{238}U(n,f)/^{235}U(n,f).

It is also planned to instrument the spallation target with devices registering spallation product yields in combined proton–neutron field. In particular, a helium loop passing through the target at different distances from the beam entrance point will be designed and created. Recoiled spallation products will penetrate the helium loop and will pass with a stream of He to the γ-spectroscopy setup analyzing isotope composition and absolute values of activities of spallation products. Extremely small passage time (1–5 s) permits to measure short-lived products with a good accuracy.

2.2. Radioactivity induced in the spallation target

SAD will have a replaceable spallation target, Pb and W options are foreseen with different sizes, changeable proton spot-point and different beam Fission rates actinides will be measured at SAD for different isotopes. For fission products (FP) detection the dielectric (glass) track detectors (SSNTD) will be used taking advantage of their insensitivity to types of radiation. In each measurement one array containing studied isotope and track detector will be placed in designated locations inside the core together with similar array consisting of track detector and monitoring isotope (^{235}U or ^{239}Pu).

In order to prepare accurate experimental technique for SAD, preliminary measurements have been performed using activation detectors of ^{12}C, ^{27}Al, ^{59}Co, ^{63}Cu, ^{115}In, ^{197}Au, ^{209}Bi with Pb and W targets.

Activation measurements compared with simulation results for distribution of hadrons along the Pb-spallation target are presented in Fig. 4 [9].

For quantitative evaluation some nuclides were selected to study their axial distributions inside the Pb target. The results for ^{210}Po are presented in the Fig. 5.

2.3. Kinetics of SAD

One of the most important tasks for studies of subcritical systems is measurement and monitoring of reactivity in particular in deep subcriticality.

Special experiments are foreseen on the existing fast neutron pile (BFS in Obninsk) in SAD-like configuration with a small pulsed neutron generator (PNG—10^8 n/s, 1 μs pulse width, 20 Hz repetition rate). Experiments will be performed starting from reference critical configuration down to a deep subcriticality. Based on these experiments an experimental technique will be developed accumulating all experiences from MUSE, YALINA subcritical experiments and JINR experiments with IBR-30 booster. The experimental technique developed during experiments on BFS will be transferred directly to the SAD facility and applied during the physical start-up.

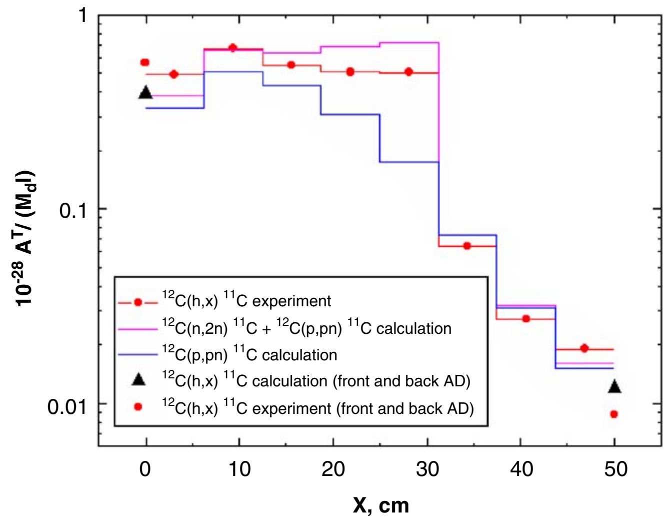

Fig. 4. Distribution of specific radioactivity of the C detectors located on a surface of a Pb target.

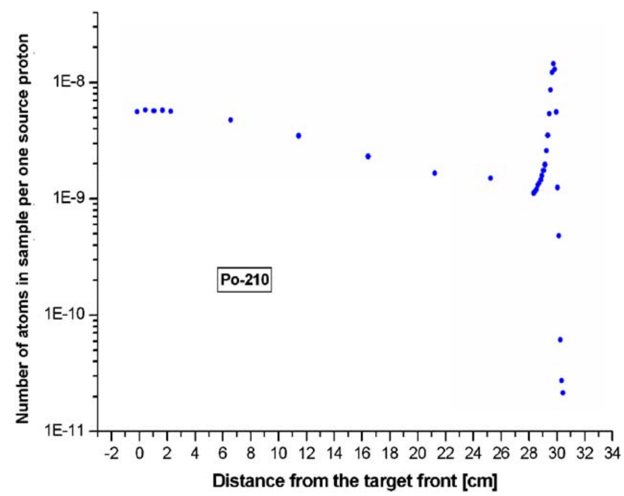

Fig. 5. Distributions of the ^{210}Po activity in ^{209}Bi samples along the Pb target irradiated with 660 MeV protons.

3. Radiation protection and shielding aspects of high-energy neutrons and protons

Spallation neutron source driven by 660 MeV proton beam generates neutrons with energy up to impinging proton energy and therefore requires special attention to be paid to shielding aspects. Those high-energy neutrons emerging from the spallation target create new challenges for radiation shielding.

There are some options considered for radiation shielding experiments:

1. Activation methods using the simple reactions, such as ^{209}Bi(n, xn)$^{209-x}$Bi, ^{27}Al(n, α)^{24}Na and spallation products on ^{197}Au target.
2. For measurements of neutron spectrum and attenuation of high-energy neutrons, activation detectors are foreseen in slots in the concrete shield at different locations.

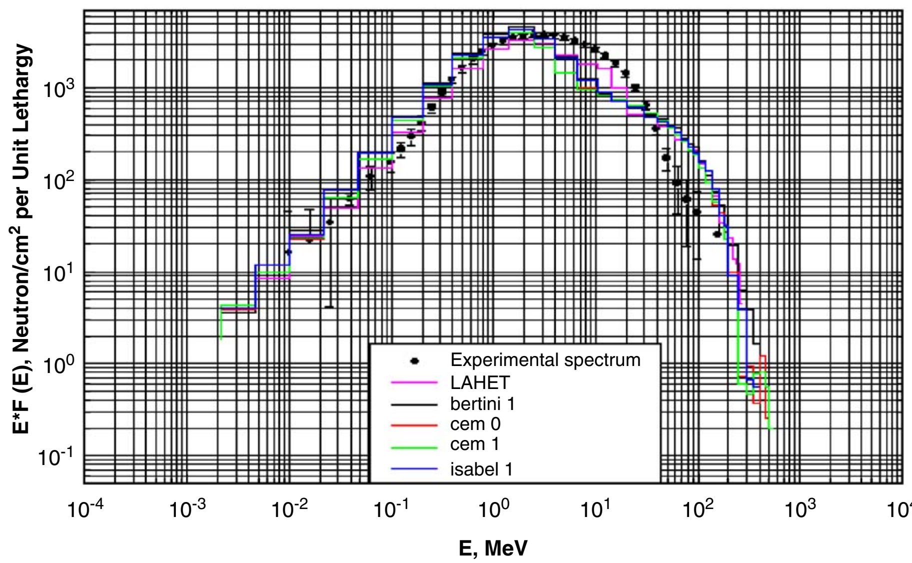

Fig. 6. Comparison of experimental results of the neutron spectra measurements at the specified angle with computer simulations of LAHET and MCNPX using different options for high-energy interactions.

3. For measurement of high-energy neutron spectrum behind the shield proton recoil method is considered.
4. Bonner spheres can be used in different locations.

An example of measurements of neutron spectra around the Pb target with Bonner spheres method is presented in Fig. 6 [10].

The details of this experiment do not fit into the frame of this publication but it can be concluded that differences between various high-energy transport models used in LAHET and MCNPX codes seem to be very small for this type of experiments and much more refined measurements and better statistics in simulations are needed to make any conclusions concerning the performance of the specific models. This is in principle a good message for those who simulate ADS, i.e., neutron yields and their spectra in high-energy region are not very sensitive on different models used for high-energy transport simulations.

4. Conclusions

SAD facility if aggressively pursued may be operational in 4 yr opening new experimental possibilities for the international ADS community.

Moreover, the experimental program of SAD is well adjusted to the objectives of the European Project "Eurotrans" and may significantly contribute to this project.

Many supporting experiments have already been conducted and produced valuable data.

Acknowledgments

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