WHITE BOOK

on the

Future of Low-Energy Nuclear Physics in Poland

and the

Development of the National Research Infrastructure

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three different scattering targets, of which one is either liquid deuterium or hydrogen (from 2 to 10 mm thick). The remaining positions are usually used for mounting a ZnS screen for on-line beam spot observation, solid targets (CH_2 and/or CD_2) or various auxiliaries for halo or background studies.

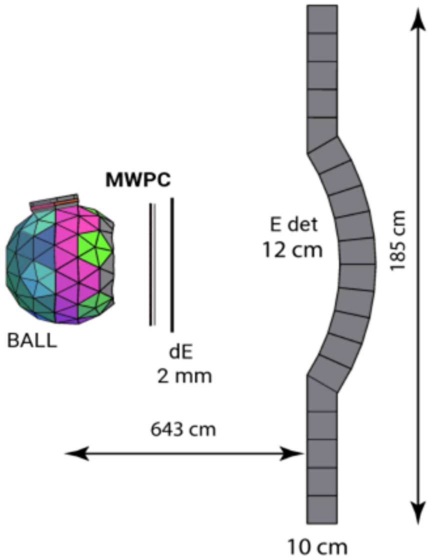

Fig.9 *Schematic side view of the BINA detector.*

In addition to the two main nuclear physics activities described above, other topics are studied: structure of single-particle states close to the particle evaporation threshold, investigation of the mechanism of proton-induced fission and spallation, modelling hadron therapy by gamma-rays, and, last but not least, in-beam testing of novel detectors constructed for large infrastructures, e.g. CALIFA, PARIS or FAZIA.

Concerning the future upgrading of the experimental part of CCB, new detector systems, such as, for example, an array of small $LaBr_3$ scintillators, a germanium array and a tape station for studies of isomeric decay of exotic nuclei from fission or spallation processes are being considered. In the more distant future, an additional, larger experimental hall is under discussion.

3.4 Nuclear Physics at Extremely Low Energies: A Small Accelerator System under Ultra High Vacuum Conditions

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A new accelerator system is a central part of the eLBRUS (Laboratoria Badawczo-Rozwojowe Uniwersytetu Szczecińskiego) laboratories situated at the University of Szczecin. Other laboratories of eLBRUS such as the Laboratory for Radiospectroscopy and the Laboratory for Optoelectronics are also equipped with modern facilities, for instance a superconducting nuclear spin spectrometer or high intensity lasers, and can be used for some diagnostic purposes of nuclear experiments at very low energies which are mainly devoted to astrophysical problems of the creation of the chemical elements in the universe or to applied research relevant to developing new nuclear energy sources based both on nuclear fusion and fission. Likewise, some radiobiological studies can be performed.

However, the main aim of the new accelerator system is to study nuclear reactions at the lowest possible energies for which atomic degrees of freedom are important and the target surface should be atomically clean. These two conditions define all the important parameters that determine the uniqueness of the entire system. Since the investigated reactions take place far below the Coulomb barrier and the corresponding cross sections decrease very fast with the diminishing projectile energies, we need a high current ion source with very good energy definition. Target cleanness is important because any target surface impurities lead to a reduction in the energy of the projectiles and disturb the atomic processes we would like to study. Thus, ultra-high vacuum (UHV) conditions at the target chamber as well as surface physics diagnostics of the targets used are necessary.

The system, finally equipped at the end of 2015, consists of two independent parts manufactured by different companies: the accelerator and beam transport system (Dreebit GmbH, Germany) and the UHV target chamber with diagnostic equipment (PREVAC, Poland), see Fig.10. The 2.7 GHz ECR ion source with permanent magnets can provide light and heavy ion beams (up to Ar) of high currents (up to several mA deuteron beam on target) with a long-term energy resolution of a few eV. A 90° double focusing analyzing magnet and system of magnetic and electrostatic focusing elements delivers the ion beam through the units of the differential pumping system to the target chamber. The target chamber (Fig.10 right) is built of mu-metal to shield the magnetic field and to enable electron spectroscopy of the target surface. It works under UHV conditions with a pressure down to 10^{-11} mbar and is equipped with an electron gun operating together with a high-resolution electrostatic electron detector. Thus, Auger electron spectroscopy (AES) can be utilized for investigation of the cleanness and structural contamination of the target surface.

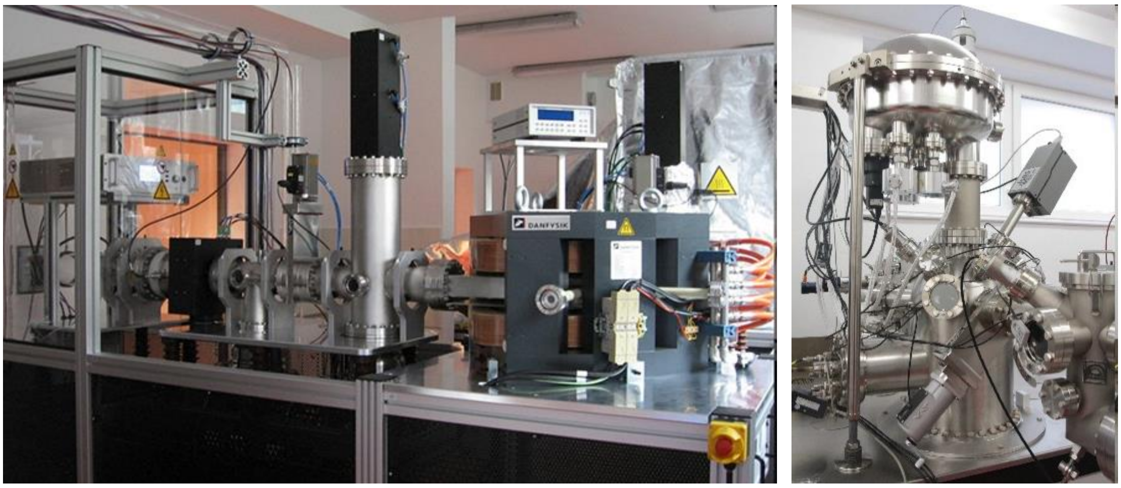

Fig.10 *The UHV accelerator system at the University of Szczecin. Left: ECR ion source and analyzing magnet. Right: Target chamber*

Targets are placed in the center of the chamber on a 5-axes manipulator combined with a laser positioning system. The targets, mounted on a transportable target holder, can be cooled down to -170°C and heated to 1200°C and are moved by a linear transfer system from a load lock chamber to avoid unnecessary ventilation of the whole target chamber. Two different detection systems of charged nuclear reaction ejectiles can be used. A close geometry system is based on an Si detector telescope setup that enables the largest possible detection solid angle to be covered. The second detection system is designed for measurements of reaction angular distributions and consists of many large area Si detectors placed at larger distances from the target. A combination of both systems depending on experimental requirements is possible.

An example of experimental results obtained at the UHV accelerator system is presented in Fig.11 where the reaction enhancement factor, defined as the ratio of the experimentally determined cross section for the ^{2}H(d,p)^{3}H reaction taking place in a metallic Zr environment, to the theoretical cross section describing gas target experiments is depicted.

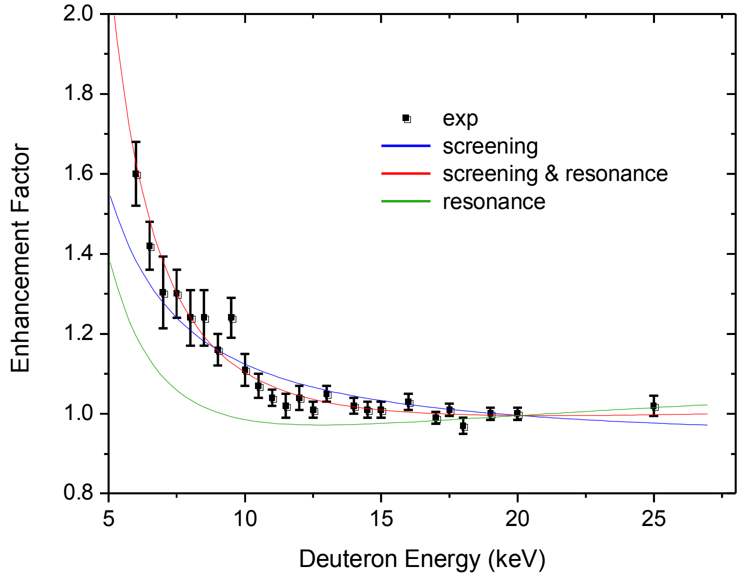

Fig.11 *Enhancement factor for the ^{2}H(d,p)^{3}H reaction, contributions due to the threshold resonance and electron screening effect [1].*

The enhancement observed at deuteron energies below 10 keV probably results from two effects: the electron screening effect and the contribution of a new threshold resonance. The first one is due to shielding of the Coulomb barrier by quasi free metallic electrons, and the second one could be recognized for the first time because of a destructive interference between different cross section components leading to a flat energy dependence of the enhancement factor for energies above 10 keV. However, to distinguish unambiguously different contributions, a measurement at deuteron energies down to 1 keV, for which the cross section could be increased even by a factor of several thousand, is needed and important for both nuclear astrophysics and the fusion reactor technique.

The UHV accelerator system at the University of Szczecin should, therefore, be improved in the near future by an additional deceleration/acceleration unit placed in front of the target chamber. In the case of the 1 keV measurements, it will allow operation of the ECR ion source at higher voltage to get higher deuteron currents and simultaneously reduction of the deuteron energy before impinging on the target. On the other hand, the acceleration mode of the additional unit can increase the total energy of the ion beam to about 100 keV per charge unit, which will open a new field for our investigations – we plan to study crystal lattice damage induced by heavy ions in structural materials of future fission and fusion reactors. The interaction with matter of heavy ions is much more effective than that of neutrons and thus can simulate neutron irradiation in reactors. In Fig.12, the influence of crystal lattice defects on the enhancement factor in the d+d reaction is demonstrated – changing the electronic band structure of the target can change the nuclear cross sections. For this kind of experiment the target chamber will be additionally equipped with X-ray and UV sources to apply XPS and UPS spectroscopic diagnostic methods. Furthermore, increasing the ion energies will enable the use of neutrons from the $^2H(d,n)^3He$ reaction for radiobiological studies of the non-linear response of biological samples to ionizing radiation and to continue our research [2] performed till now in other laboratories.

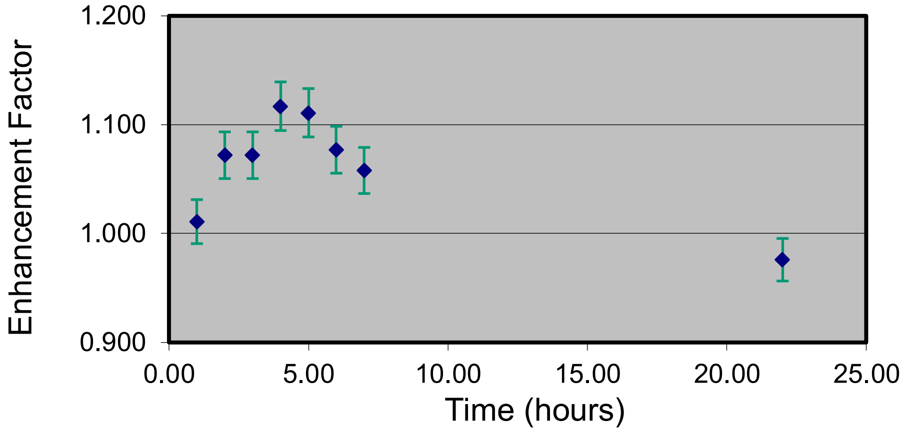

Fig.12 *Dependence of the enhancement factor on the irradiation time at a deuteron energy of 14 keV. The increase during the first 5 hours results from the crystal lattice defects.*

References:

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[2] A. Kowalska, E. Nasonova, K. Czerski, P. Kutsalo, W. Pereira, E. Krasavin, Radiation and Environmental Biophysics, 2019

3.5 The MARIA research reactor with the Interdisciplinary Laboratory of Materials and Biomedical Research

(current status and perspective for 2050)

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The MARIA nuclear research reactor is (after the shut-down of the former EWA reactor on February 24, 1995) the only nuclear reactor operating in Poland. Its nominal thermal power is 30 MW. It is an experimental and production reactor currently designed for the following purposes:

- irradiation of materials for the production of radioisotopes,
- materials engineering and technological research,
- development and testing of nuclear measuring and diagnostic systems and subassemblies,
- neutron doping of semiconductor materials,
- neutron modification of materials,