ACTIVITIES FOR ISOTOPE SAMPLE PRODUCTION AND RADIATION EFFECT TESTS AT JULIC/COSY JÜLICH

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Abstract

At the Forschungszentrum Jülich (FZJ) the intermediate energy cyclotron JULIC, used as injector of the Cooler Synchrotron (COSY), and at the COSY itself, over the last years, have been enabled to perform low to medium current irradiations. Main task is to support the FZJ radionuclide research programme of INM-5, by developing, adapting and optimizing the irradiation facilities. The INM-5 target holders were implemented via an adapter section to the external target station of JULIC to obtain reliable irradiations with 45 MeV protons and 76 MeV deuterons, both for nuclear reaction cross section measurements and medical radionuclide production. For testing of radiation effects, displacement damage (DD) and single event effects (SEE), with energetic protons for electronics used in space and accelerators the beam can be extracted to a dedicated test stand, e.g. used by Fraunhofer INT. To provide these possibilities at higher energies up to 2.5 GeV as well one external beamline of the cooler synchrotron COSY is going to be equipped with a new irradiation vacuum chamber to separate the irradiation zone from the COSY-vacuum system and adaption for the dosimetry systems are done. Different dosimetry systems (PTW® Farmer ionization chambers, PTW® Bragg Peak chambers, Gafchromic® Dose sensitive foils) are available to monitor and control the ongoing irradiation. This report briefly summarizes the relevant technical activities.

INTRODUCTION

The Institute for Nuclear Physics (IKP) [1] is focusing on the tasks given by the Helmholtz Association (HGF). This comprises the design and preparations for the High Energy Storage Ring (HESR) of FAIR [2] with the PANDA experiment. The on-going hadron physics program at the Cooler Synchrotron COSY exploits the internal experimental set-up PAX. The extracted beam is used for the PANDA experiment, detector tests and also for high energy irradiation in the area of the finished TOF experiment. IKP is part of the section “Forces And Matter Experiments” (FAME) at the Jülich-Aachen Research Alliance (JARA). This joins scientists and engineers from RWTH Aachen and Forschungszentrum Jülich for experiments, theory and technical developments for anti-matter (AMS) and electric dipole moment experiments (EDM). The institute is member of the HGF project Accelerator Research Development (ARD) and pursues research on various accelerator components. The future project Jülich Electric Dipole Moment Investigation (JEDI) [3] will profit from the availability of polarized beams from the injector cyclotron and the unique capabilities and experiences at the COSY facility.

CYCLOTRON OPERATION

The COSY accelerator facility [4, 5], operated by the Institute for Nuclear Physics (IKP) at the Forschungszentrum Jülich GmbH, consists of the injector cyclotron JULIC and the Cooler Synchrotron COSY. Both accelerators are originally dedicated to fundamental research in the field of hadron, particle, and nuclear physics, to study the properties and behavior of hadrons in an energy range that resides between the nuclear and the high energy regime.

The cyclotron JULIC provides 45 MeV H^- respectively 76 MeV D^- with max. beam currents of ~10 µA. Operation of the cyclotron started 1968 and beside the Nuclear Physics experiments a small amount of the available beam time was used for irradiation. In the beginning the irradiations were performed with internal targets inside the cyclotron. But since the implementation of the target holders of the INM-5 at the external target station of JULIC via an adapter section [6], reliable irradiations can be done both for nuclear reaction cross section measurements and medical radionuclide production. In the case of the deuterons, the emphasis is on cross section measurements because the data base for many of the deuteron-induced reactions is weak. The proton beam, on the other hand, is mainly used for the production of the important β^+ emitter ^{73}Se via the $^{75}As(p,3n)$-reaction over the energy range of E_P = 40 → 30 MeV at beam currents of a few micro amps. A view of the adapter at the end of the beam line is given in Fig. 1.

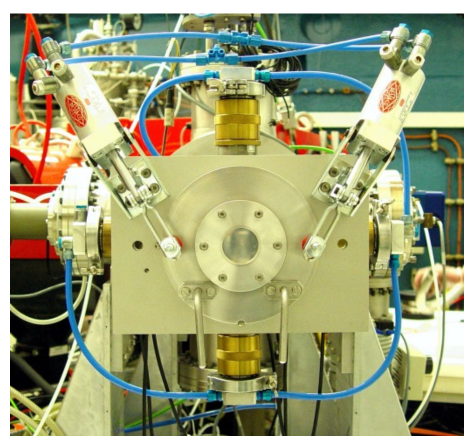

Figure 1: Head of adapter section at the external JULIC beam line.

For the last 15 years Fraunhofer INT with IKP have been operating a dedicated radiation effects test facility at an external beam line of the JULIC cyclotron [7], which can be seen in Fig. 2. Since the tests are performed in air,

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the beam has to pass a 1 mm Al foil and about 1.8 m of air, which reduces the energy of the protons to 35 MeV at the surface of the target [8].

Figure 2: Beamline for Radiation Tests at JULIC.

IRRADIATION FACILITY AT COSY

The Cooler Synchrotron COSY, commissioned in 1993, provides protons and deuterons in the broad energy range from 20 MeV up to 2.5 GeV [9] by de- or accelerating the beam. The number of particles is up to 10^{11}/spill. COSY has three external beam lines (see Fig. 3) useable for testing of detector systems, accelerator components, investigations on radio-isotope-production properties or for radiation effects tests.

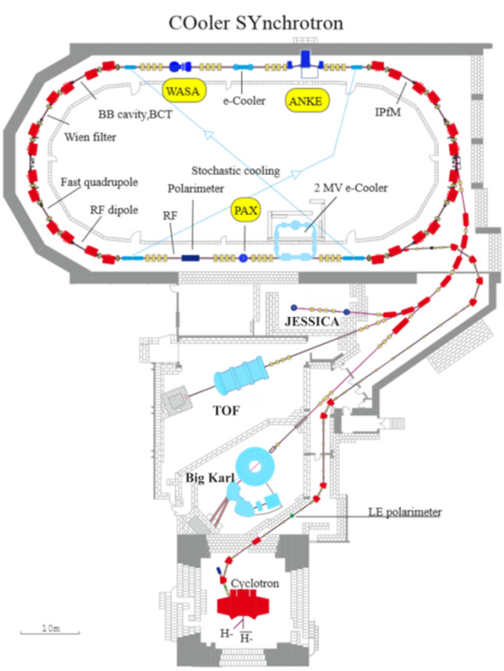

Figure 3: Layout of the COSY facility (with TOF- and Big Karl-Detector).

COSY operation has been very reproducible and reliable with ~7000 h/year. Two different extraction schemes have been used; Fast Kicker Extraction with 10^9p within 200 ns [10] and in contrasts the Slow Extraction with variable beam currents of 10^{10} p/s down to 10^4 p/s, depending on the extraction times (Fig. 4).

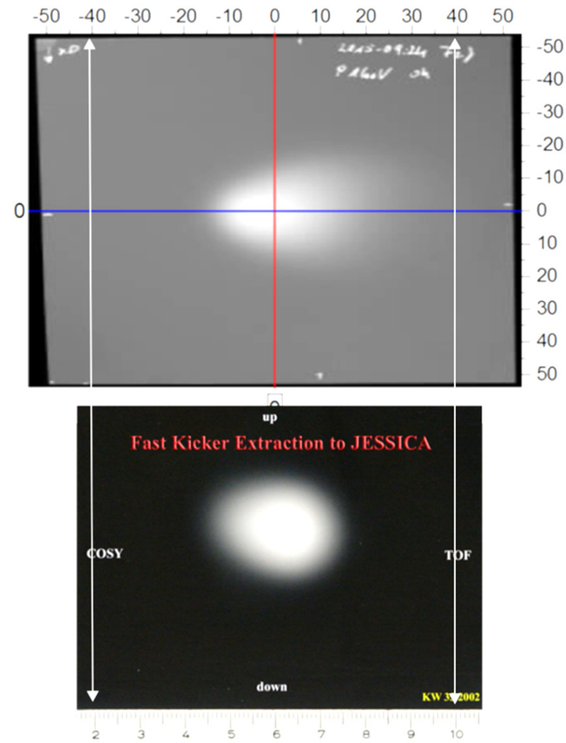

Figure 4: Beam spots at JESSICA target place with Slow Extraction (2015,up) and Fast Kicker Extraction (2002, down). The Beam spots are of similar size.

Twice a year the COSY Beam Advisory Committee (CBAC) examines applications for experiments to be carried out at COSY. Within the beam time request energies, particle numbers, safety aspects, additional things and at least the necessity of the experiment is asked for. This will be described in a short beam time proposal.

EXTERNAL EXPERIMENTAL AREAS

Since the research programs with JESSICA, TOF and Big Karl-Detector Systems ended in 2015, the detectors were dismounted and the areas cleared for new tests. While the TOF-area is intended for tests of PANDA-related detector and data-acquisition systems the other two areas are foreseen for changing installations like irradiations, detector- or radiation effects tests.

Therefore the Big Karl area as well as the JESSICA area is equipped with adjusted 3m long tables whereon different experimental setups can be mounted easily. The distance between table and beam is about 50 cm.

In addition there are remotely operable X-Y-tables to change between different probes, e.g. Fig. 5. The X-Y-tables are operated via Labview® but can be accessed via serial connection directly as well.

A vacuum chamber for irradiation has been constructed by INM-5, which is shown in Fig. 5. It will allow irradiation, separated from COSY vacuum of thin foils in a stack geometry and collection of charge in a Faraday cup. Activation studies of several potentially useful radionuclides e. g. ^{52}Fe, ^{67}Cu, ^{72}Se, etc. [11, 12], for which the database is weak and the production methods need improvement. They could be advantageously produced only if proton

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beams of intermediate energy (between 50 and 150 MeV) would be available. First results using beam intensity in the nA scale are expected to commence soon.

Radiochemical separations and yield measurements will follow and be performed at the INM-5. In the first phase clinical scale production is not envisaged. It may follow if a higher current beam could be made available in due course of time.

The Big Karl area is rather big. The available length for installations behind the beam exit is about 10 m. The JESSICA area with available length of 3 m only is much more compact. The heights of the beamlines differ (TOF 2.19 m, in JESSICA 1.75 m and in Big Karl it is 1.42 m). Transverse beam spots are variable. In TOF and Big Karl it is minimal 2-3 mm while in JESSICA it is 20 mm (Fig. 4) due to absence of focusing elements. This is going to be improved; beam tracking calculations are in progress. The beam spots can be widened up to 20cm diameter.

The proton beam extraction at the chosen irradiation position is being optimized with respect to energy, shape and intensity. All beam lines are equipped with ionization chambers to measure beam current and multi wire proportional chambers (MWPC) for beam position measurements. In terms of low energy particles these measurements are destructive to the beam and are done before the irradiation or afterwards only.

Figure 5: View into the "new" Big Karl area with test setup for Radiation effects tests and the “irradiation chamber”.

To monitor and control fluence and homogeneity during the ongoing irradiation up to 12 PTW® Farmer Ionization Chambers Type 30010 and 2 PTW® Bragg Peak Chambers Type 34080 are available and can be connected via a connector-box 12xM T16007 to a PTW MULTIDOS T10004 Multichannel dose meter.

The data-visualization and acquisition is done with Labview®-Programs taking all Dosimetry-data as well as other important measures like humidity, temperature, pressure e.g. all data are stored and can be processed later. Figure 6 is showing a dose measurement at JESSICA and gives an impression on the stability and reproducibility in terms of short (shot to shot) as well as of long term operation of COSY.

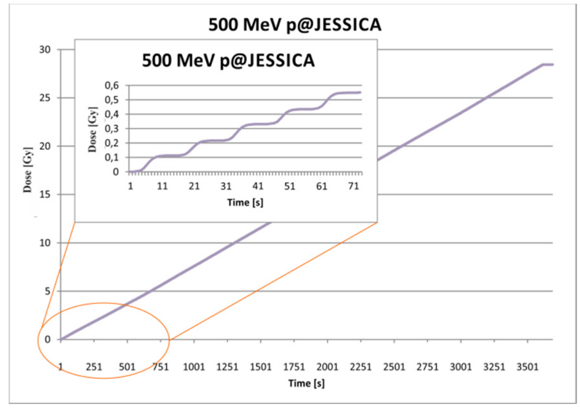

Figure 6: Irradiation at JESSICA, 500 MeV Protons over 1h to the target. The small picture shows the time structure with filling COSY, accelerating the beam and extraction to the target while the big one gives the stability.

In addition Gafchromic® self-developing foils Type EBT3 and EBT XD can be used for checking homogeneity of the irradiation as well (Fig. 7). The readout is done with an Epson® 11000 scanner. For analyzing the foils FilmQA Pro from Ashland® is available.

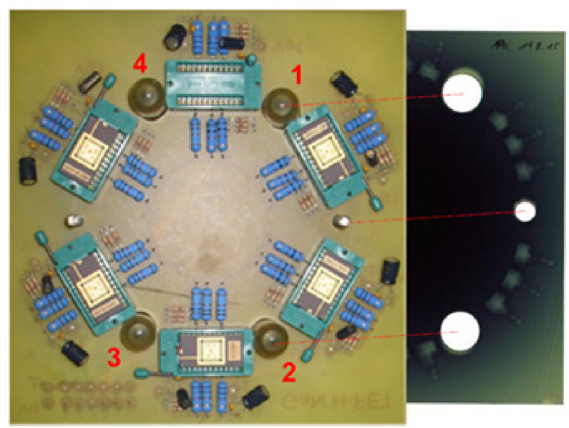

Figure 7: Test of electronic devices; Dosimetry is done with 4 Farmer chambers and a EBT3-background foil.

CONCLUSION

At the COSY accelerator facility irradiation and radiation tests with protons as well as with deuterons can be performed in the broad energy range from 20 MeV to 2.5 GeV. Three external beam lines at COSY as well as one beam line at JULIC are useable for these tests or irradiations. Available intensities can be varied from 10^{10} p/s down to 10^{4} p/s by slow extraction over long times.

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