A NEW MONO-ENERGETIC NEUTRON BEAM FACILITY IN THE 20-180 MeV RANGE

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Abstract

Recent interest in nuclear applications involving neutrons, like transmutation of nuclear waste, fast-neutron cancer therapy, dose to personnel in aviation and electronics failures due to cosmic-ray neutrons, motivates the development of a facility producing intense mono-energetic neutron beams. At The Svedberg Laboratory (TSL), Uppsala, Sweden, we have developed such a facility by utilizing the existing cyclotron and inserting a flexible Lithium target in a rebuilt beam line. The new facility can operate at unsurpassed quasi-monoenergetic neutron intensities and provides large flexibility of the neutron beam properties, like energy and shape.

INTRODUCTION

The need for a detailed understanding of nuclear interaction of neutrons is driven by a large number of different applications. Transmutation of nuclear waste [1] is one application that may provide a solution to the problem of long-lived nuclear waste storage. The materials used in, for example, the containment of the transmutation reactor are exposed to extreme neutron fluxes that will affect the material properties. Understanding the involved mechanism is essential to guarantee the reliability of the transmutation plant.

The second field of applications is based on the interaction of neutrons with biological matter that needs to be understood thoroughly in order to design treatment plans for fast neutron therapy. The increased radiation dose due to the effect of neutrons generated in cosmic ray cascades that air-plane personnel is exposed to [2] needs to be investigated in order to draw proper radiation protection guidelines for them.

The third field of applications is motivated by the quest for smaller structures in the semiconductor industry which causes the logical states in memory chips to be represented by only a relatively small number of electrons. Thus, the indirect ionization caused by nuclear reactions of neutrons that originate from cosmic ray cascades can alter the logical state of the semiconductor memory cells or cause a burnout in high-voltage power diodes [3] which poses a significant threat for their reliability. In particular, mission-critical applications such as computers in airplanes are reasons for concern.

Careful testing of these neutron-induced single-event effects (SEE) in semiconductor materials [4] using the natural flux of cosmic neutrons is very time-consuming. To speed up the measurements, one needs to use neutron beams produced with particle accelerators. This has led the standardizing body of the electronics industry (JEDEC) to establish a standard for the procedures for accelerated testing of memory devices. The standard is summarized in Ref. [5] and states that one of the ways to perform the accelerated testing is to irradiate a device under study by monoenergetic neutrons with nominal energies of 20, 50, 100, and 150 MeV. Such an approach is a viable alternative to the testing with a *white* neutron spectrum, if the intensity of mono-energetic neutrons is enough to cause reasonably high SEE rates.

To satisfy these needs, an upgrade of the old neutron facility [6, 7] at The Svedberg Laboratory (TSL) has been undertaken with the primary goal to increase the neutron beam intensity and, thereby, to make the facility competitive for SEE testing and for studies of SEE mechanisms. In addition, the new facility offers an unsurpassed flexibility of the neutron beam properties, like energy and shape.

THE NEW FACILITY

A drawing of the new neutron beam facility is presented in Fig. 1. The facility makes use of the proton beam from the Gustaf Werner cyclotron [8] with the energy variable in the range 20 to 180 MeV. The proton beam impinges on a target of Lithium, enriched to 99.99 % in ^{7}Li with a thickness of $2, 4, 8, 16$, and 24 mm. The targets are rectangular in shape, 20×32 mm, and are mounted in a remotely controlled water-cooled copper rig. An additional target position contains a fluorescent screen viewed by a TV camera, which is used for beam alignment and focusing. Downstream the target, the proton beam is deflected by a magnet into a 10-m long dumping line, where it is guided onto a heavily shielded water-cooled graphite beam dump. In order not to preclude the later installation of a kicker that can be used to alter the time structure of the proton beam by kicking one out of two proton bunches such that they miss the Lithium target, we have avoided quadrupoles in the dump line, because they would have to have very large apertures. We chose to use a wide beam pipe with a diameter of 40 cm to prevent excessive proton beam losses to

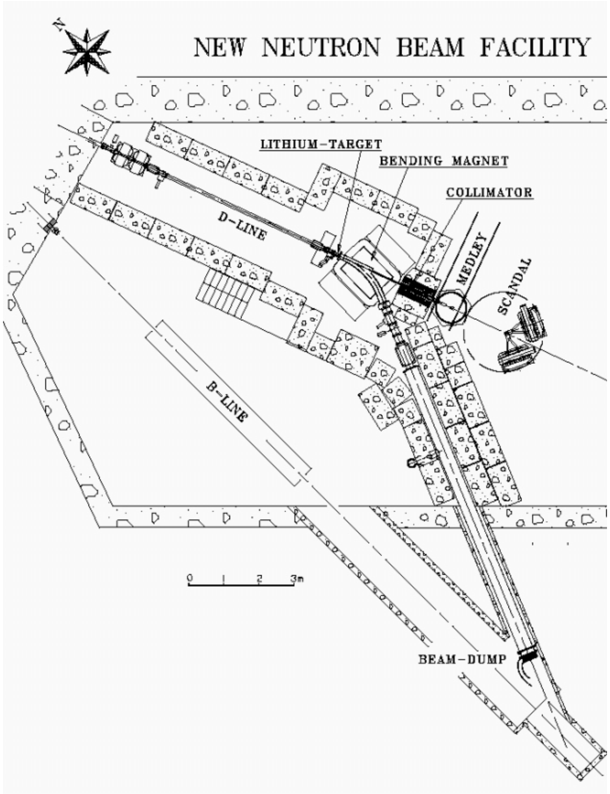

Figure 1: *Drawing of the new neutron beam facility.*

cause background for the experiments.

The neutron beam is geometrically formed by a cylindrically shaped iron collimator block, 50 cm in diameter and 100 cm long, with a cylindrical or conical hole of variable diameter. The collimator is surrounded by concrete to form the end wall of the production line towards the experimental area. Thereby efficient shielding from the production target region is achieved. A modular construction of the collimator allows the user to adjust the diameter of the neutron beam to the needs of a specific experiment. At present, the available collimator openings are 2, 3, 5.5, 10, 15, 20, and 30 cm. Other collimator diameters in the 0-30 cm range, as well as other shapes than circular can be provided upon request. Even beam diameters of up to 1 m are obtainable at a larger distance from the production target. The increased diameter of the beam may be used for testing a larger number of devices simultaneously, or a larger device like the whole electronic wafer.

After passing the collimator, neutrons reach the experimental area at a distance of about 3 m from the production target. Reduction of this distance to the minimum has led to an increase of the neutron flux by about one order of magnitude in comparison with the old TSL neutron facility.

The first neutron beam at the new facility was delivered in January 2004. At present, commissioning of the facility is being performed, including optimization of beam transport, diagnostics, vacuum and background conditions, as well as measurements of neutron flux, spectra, and profile.

The typical neutron flux during the test run amounted to about 5×10^5 /(cm^2 s) at the entrance to the experimental area. This value is about one order of magnitude larger than at the old neutron facility at TSL [6, 7] with the same target thickness, proton energy and current.

The dumping efficiency, i.e. the share of primary protons that reach the beam dump after passing the Lithium target, was typically 90-95%. Taking into account the uncertainty in the current measurement of about 10% and loss of protons due to nuclear reactions in the target (up to 2% depending on proton energy and target thickness), this is acceptable.

The measured contamination of the neutron beam at the experimental area due to interactions of the primary protons with elements in the beam line such as the target frame did not exceed 0.2%. Such interactions only lead to a weak surplus of neutrons in the experimental area, because charged particles produced near the Lithium target and upstream are removed by the deflection magnet. The relative contamination with protons in the neutron beam that have energies above 15 MeV is about 10^{-5}.

EXPERIMENTS

The energy and angular distribution of neutrons at the experimental area is mainly defined by the double-differential cross-section of the ^{7}Li(p,n) reaction at forward angles. The reaction energy spectrum is dominated by a peak situated a few MeV below the energy of the primary protons. Thus, the facility is capable to deliver neutrons in the 20 to 175 MeV range. This makes TSL the only laboratory offering fully monoenergetic neutron testing according to the JEDEC standard [5].

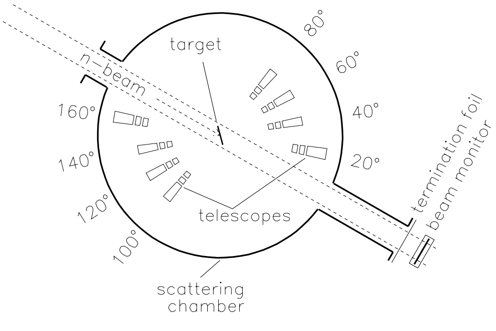

Figure 2: *The Medley detector*

Apart from experimental stations for direct irradiation two detectors, Medley and SCANDAL, are available to detect the reaction products of neutron induced reactions. The Medley setup [9] has been constructed for detection of light ions, ranging from protons to alpha particles, with an almost complete coverage both in energy and emission angle. Figure 2 shows a schematic view. The spectrometer consists of eight detector telescopes, housed in a scattering chamber with 80 cm inner diameter. The telescopes are mounted on rails, allowing the distance to the target to be varied. In the standard configuration, the telescopes are located at 20 degree intervals, ranging from 20 to 160 degrees emission angle. This can be changed by mounting the rails differently. The entire setup is mounted onto a plate which can be rotated from outside.

Each telescope consists of three detectors; a thin silicon detector (50 to $60\,\mu$m), a thicker silicon detector (400 to $500\,\mu$m) and a CsI(Tl) crystal, about 3 cm thick. Using different combinations of detectors for different energy ranges, the charged particles can be identified by ΔE-E techniques, and their energies can be determined down to about 2 to 3 MeV. The upper energy limit is about 130 MeV for protons.

The SCANDAL detector [7], see Fig. 3, detects neutrons and light ions in the 20 to 130 MeV energy interval but is primarily intended for neutron detection. The setup consists of two identical telescopes, located on each side of the neutron beam, and movable around a pivot point. For proton measurements, each telescope contains two plastic scintillators for triggering, two drift chambers for tracking, and a CsI(Na) detector array for energy determination. In neutron mode, a plastic scintillator converter is added for active conversion of neutrons to protons, and a veto detector is placed in front of the converter to reject charged particles from the target.

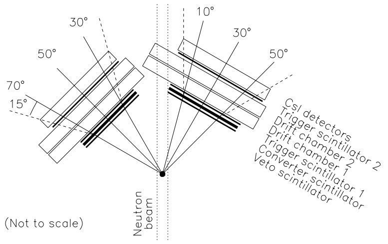

Figure 3: *The Scandal detector*

FIRST RESULTS

The high-energy peak in the neutron spectrum comprises about half of the total number of neutrons. Further details on the neutron spectra from the ^{7}Li(p,n) reaction may be found in Ref. [10]. Dedicated measurements of the facility neutron spectrum and the neutron beam profile at the experimental area are under way. A first preliminary result of a neutron spectrum from the new facility is shown in Fig. 4.

CONCLUSIONS

A new neutron facility, optimized for SEE testing, has been constructed and put into operation at TSL, Uppsala, Sweden. The SEE rate at the new facility exceeds that of other facilities by a factor of ten. TSL is the only laboratory offering full monoenergetic neutron testing according to the JEDEC standard. In addition, TSL offers testing with protons in the 20 to 180 MeV energy range, and with a wide range of heavy ions. Thus, TSL has the unique feature to provide neutron, proton, and heavy ion testing in the same laboratory.

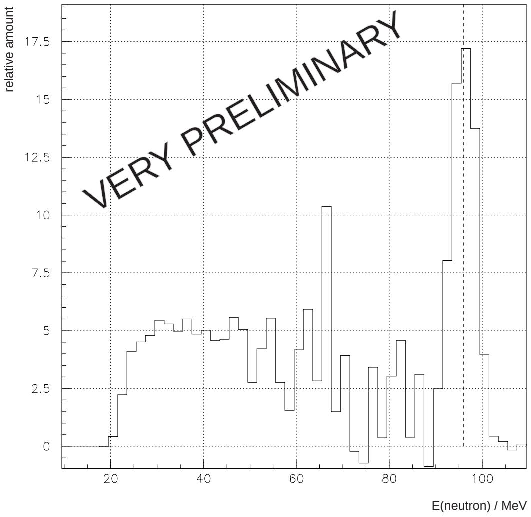

Figure 4: *Preliminary neutron spectrum from the new facility.*

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