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UPGRADE OF THE FAST NEUTRON BEAM VAULT AT iTHEMBA LABS TO A METROLOGY FACILITY

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Abstract

Quasi-monoenergetic neutron beams are typically produced at the iThemba LABS fast neutron beam facility by the ^{7}Li(p,xn) or ^{9}Be(p,xn) reactions. With the proton beams available from the separated sector cyclotron, the neutron energy range from about 30 MeV to 200 MeV can be covered almost continuously. The facility first became operational in the late 1980s. The fast neutron beam facility at iThemba LABS has been designated by the National Metrology Institute of South Africa (NMISA) as an entity responsible for providing traceability for the medium and high-energy neutron measurements in South Africa. As a result, the facility is undergoing a major upgrade and development in order for it to meet the requirements for a medium and high-energy neutron metrology facility. As part of the ongoing upgrade, Monte Carlo (MC) simulations aimed at benchmarking the experimental data are ongoing.

INTRODUCTION

iThemba LABS (Laboratory for Accelerator-Based Sciences) is one of the few facilities in the world that can provide quasi-monoenergetic neutron beams in the energy range of up to 200 MeV [1]. Quasi-monoenergetic neutron beams that range from about 30 MeV to 200 MeV are produced in the D-line experimental vault (Fig. 1) via the ^{7}Li(p,xn) or ^{10}Be(p,xn) reactions [2] for varying thicknesses of Li and Be targets, using proton beams available from the separated sector cyclotron (SSC). The iThemba LABS neutron beam facility has been designated by the National Metrology Institute of South Africa (NMISA) as an entity responsible for providing traceability for the medium and high-energy neutron measurements in South Africa. Thus, the facility is intended to be recognised and supported by the international neutron physics and metrology communities for calibrations of neutron detectors and radiation protection dosemeters; including those with a strong sensitivity to epithermal and thermal neutrons such as survey meters. Moreover, cross-section measurements of neutron-induced reactions in the medium and high-energy region (with as low uncertainties as possible) will be performed. In this regard, the neutron beam facility at iThemba LABS is undergoing a major upgrade and development in order for it to meet the requirements for a medium and high-energy neutron metrology facility.

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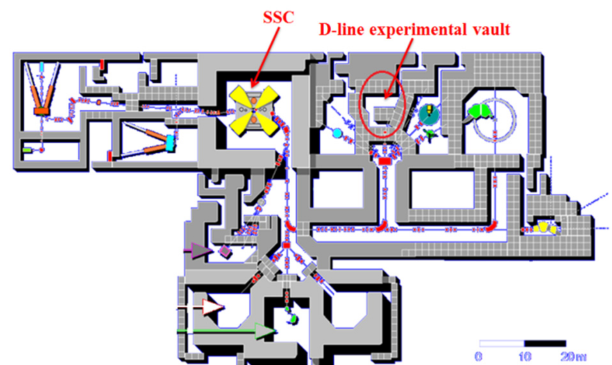

Figure 1: Layout of the iThemba LABS facility showing the location of SSC and the D-line experimental vault.

An ISO-accreditation of the facility will provide it the ability to participate in international key-comparison studies in the area of neutron metrology for medium to high-energy neutrons.

iTHEMBA LABS NEUTRON BEAM FACILITY

At the iThemba LABS neutron beam facility, neutron production targets (Li or Be) are mounted on a target ladder (Fig. 2, label 1) that has four positions, with one permanently occupied by a quartz viewer. At beam currents of a few nanoAmpere (nA), the position of the beam spot can be monitored using the quartz viewer. Out of the three other positions, one is left empty for background target runs while the remaining two are dedicated for neutron production targets. The target ladder is operated remotely. The proton beam is deflected into the beam dump after passing the target. At this point, the Faraday cup that is positioned in the proton beam dump is used to measure the beam charge. The neutron production area of the neutron beam facility at iThemba LABS is separated from the experimental area by an iron shielding wall with collimators at 0°, 4°, 8°, 12° and 16° neutron emission angles (Fig. 2). The collimator channels have rectangular cross sections of about (5 × 5) cm^{2}. Optimized neutron beam collimator inserts with conical shapes are required in order to improve the uniformity of the beam profile throughout the irradiated target.

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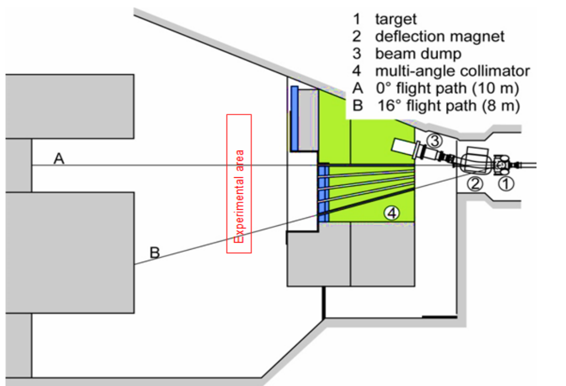

Figure 2: Layout of the fast neutron beam facility at iThemba LABS.

The lateral spatial distribution of the neutron beam depends on the positioning of the ion beam on the Li target and on the collimator shape. The collimator exits are located at a distance of 4 m from the neutron production point. Possible neutron flight paths in the D-line extend from about 4 m to about 10 m. At 0° neutron emission angle, the maximum distance from the target is about 10 m. The beam size at this position is about (13 × 13) cm^2. At 16°, the maximum distance has only been about 8 m, with a correspondingly smaller beam size. For the ongoing refurbishment plans, this 16° flight path has been extended to more than 10 m.

In order to simulate a quasi-mono-energetic neutron energy distribution via ^{7}Li(p,xn), the energy spectra of neutron beams generated by the Li + p reaction at neutron emission angles of 0° and 16° are simultaneously measured. The neutron energy distributions from these emission angles feature a prominent peak and a continuum (Fig. 3).

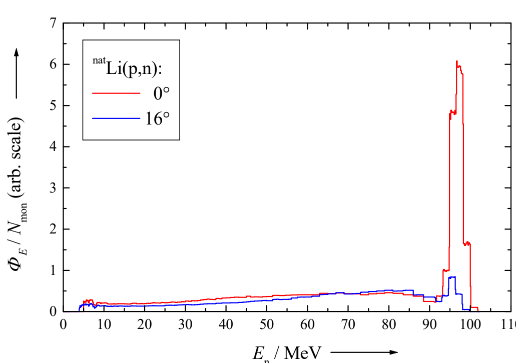

Figure 3: Neutron spectra (measured by time-of-flight) from 100 MeV protons on a 6 mm ^{nat}Li target.

The prominent peak is associated with direct reaction transitions mainly to the ground state and to the unresolved first excited state of ^{7}Be. The continuum at lower energies is associated primarily with the three-body break up process; ^{7}Li(p,n^{3}He)^{4}He. The intensity of the prominent peak in the 0° spectrum is high and rapidly decreases with increasing neutron emission angle. For the low energy continuum, the intensity is almost independent of the neutron emission angle for angles up to 16°. The yield produced by irradiation with the neutron beam in the 0° emission angle includes components due to reactions initiated by both the high-energy peak neutrons (prominent peak) and the continuum. On the other hand, the yield resulting from irradiation with the neutron beam in the 16° emission angle is dominated by reactions initiated by the low-energy continuum alone. Therefore, a yield determined for the quasi-monoenergetic neutron energy is obtained through a “difference spectrum”, by subtracting the yield produced in the 16° beam from that simultaneously produced in the 0° (Fig. 4) [3-7]. Before obtaining the “difference spectrum”, the two spectra are normalized to equalize the total number of counts in the continuum region.

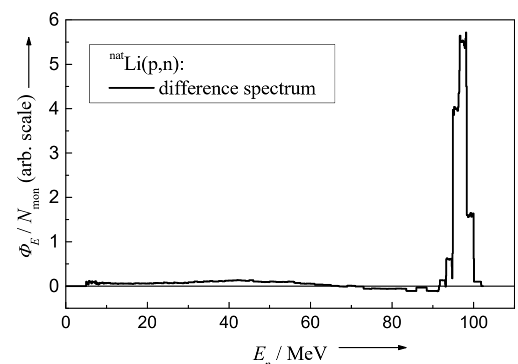

Figure 4: Difference spectrum obtained by subtracting the 16° spectrum from the 0° spectrum.

Neutron beams at iThemba LABS have been well characterized over the years [4, 7, 8]. In Fig. 5, some of the normalised neutron spectra produced at iThemba LABS are shown [9]. The intrinsic widths indicated by the red horizontal bars in Fig. 4 refer to the spread in neutron energy associated with the Li target thickness.

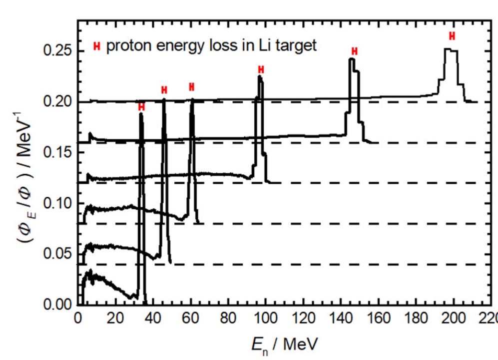

Figure 5: Normalised neutron spectra from Li targets at various energies produced at iThemba LABS [9].

The iThemba LABS neutron beam facility first became operational in the late 1980s [2, 10]. Some of the major challenges of the current set-up were identified based on the results from a measurement campaign performed in the facility by [8]. These challenges include the epithermal neutron background due to leakage from the target

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area to the experimental area (Fig. 6), instability of the spatial neutron beam profile due to movement of the proton beam spot on the neutron production target and unstable neutron energy distributions caused by protons hitting the target holder (both due to the insufficient control of the proton beam). This is unacceptable for the intended use since some of the dosemeters which will have to be calibrated in the facility tend to be highly sensitivity to epithermal and thermal neutrons.

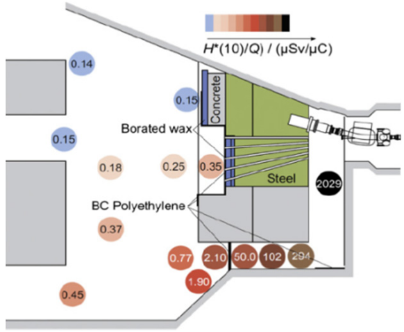

Figure 6: Ambient dose equivalent, *H*(10),* at various locations within the fast neutron beam vault at iThemba LABS measured for a 200 MeV proton beam on a 6 mm Li target [8].

FACILITY UPGRADE

As part of the ongoing upgrade, considering the findings by [8] and the advice from [10], a new design for the D-line vault is proposed as presented in Fig. 7.

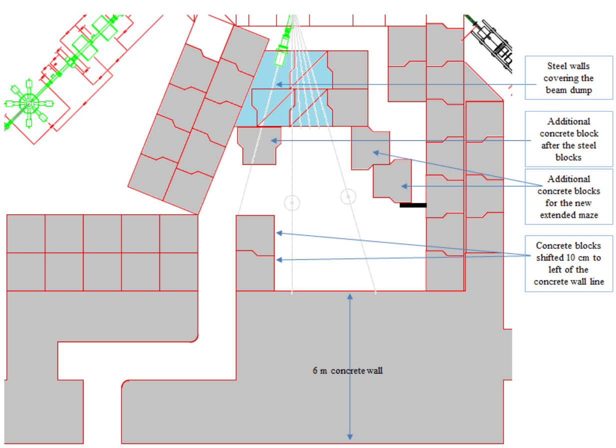

Figure 7: The proposed new configuration of the iThemba LABS neutron beam vault.

In order to reduce the effect on epithermal background, an improved shielding on neutrons from the target area was produced based on a qualitative analysis of data from the previous investigations of the neutron background using the Institut de Radioprotection et de Sûreté Nucléaire (IRSN) Bonner sphere spectrometer HERMEIS. Emphatically in this design, the leakage of epithermal neutrons from the target area through the door is reduced by additional concrete blocks. Moreover, the area between the 0°and 16° has been opened up, providing an extended 16° flight path and providing more space for the experiments. An additional concrete block (~1.5 m thick) has also been added in the vault behind the beam dump after the original steel blocks (~ 2 m thick). The layout as shown in Fig. 7 does not include an additional neutron beam dump to be installed at the end of each flight path. The neutron beam dump is meant to reduce the effect of neutrons striking the concrete wall and scattering back. This will improve shielding of background neutrons in the experimental area. The two concrete blocks along the passage have been moved 10 cm to the left (towards the passageway), in order to increase the space around the 0° measuring axis. Also, this shift has improved the direct line of sight from the beam dump towards the passageway way, which has been travelling straight to the corner of the concrete block. A test experiment aimed at validating the improved shielding in the D-line is anticipated for the beginning of 2020.

Also critical for the success of the measurements is a proper adjustment of the proton beam transport. In order to avoid parasitic sources of neutrons, the beam should have no halo and should not hit any structural material on the target chamber. Thus, the beam should be centred in such a way that only the target material is hit by the beam. At low beam currents, monitoring of the beam is accomplished by using a quartz viewer with a central hole, which takes the central part of the proton beam and makes only the outer parts of the beam to be visible on the TV screen. At higher intensities, the existing quartz viewer cannot be used since it cannot withstand higher beam currents. To enable regular on-line monitoring of the proton beam position and spot size on the neutron production target by the cyclotron operators, a radiation-hard monitor must also be installed close to the target. The expected new beam position monitoring system should be able to withstand the intended current range of ≤ 10 μA. Plans are underway to install proton beam position monitors along the beamline, which will provide continuous information about the proton beam spot during experiments. For scanning procedures, new designs for collimator insert which will provide steeper beam profiles are required and planned. Moreover, a new water-cooled target ladder, which should be able to withstand higher beam currents, will be incorporated into the system. Radiation dose levels of the facility will be investigated to test the limits on maximum beam current allowed on targets. Monte Carlo (MC) simulations aimed at benchmarking the experimental data from the D-line are ongoing. Numerous MC simulation codes are available for radiation transport using random sampling methods. For benchmarking purposes, the experiments and simulations have to be consistent in the description of the physical system for the comparison to work [11]. For the system at iThemba LABS, the standard MCNPX ver. 2.7 with tabulated values of cross-section ENDF/B-VII.0 and ENDF70prot (3007.70 h and 13027.70 h) [12] is used. As part of preparations for an ISO[1]-accreditation as a fast neutron beam reference facility, new instrumentation will be procured, characterized and tested in the D-line. In this regard, a

[1] International Organization for Standardization.

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new proton recoil telescope for 30 MeV - 200 MeV energies will be designed for fluence measurements, in addition to a modified and characterised version of the existing ^{238}U fission chamber. Moreover, a new digital data acquisition system will be procured for acquiring data during measurements. Once all the structural modifications of the vault have been done and the instrumentation optimized, the upgraded facility will be tested for metrology capabilities.

CONCLUSION

The fast neutron beam facility at iThemba LABS is undergoing a major upgrade and development in order for it to meet the requirements for a medium and high-energy neutron metrology facility. More experimental tests are planned and simulations are ongoing to benchmark the experimental data. Once the fast neutron beam facility at iThemba LABS obtains the ISO-accreditation as a fast neutron facility in the energy range from 30 MeV to 200 MeV, it will be recognised and supported by the international neutron physics and metrology communities. The facility will then be more suitable for cross-section measurements of neutron-induced reactions and for calibration of neutron detectors and radiation protection dosemeters (including those with strong sensitivity to epithermal and thermal neutrons such as survey meters). Traceability of measurements carried out using fast neutron beam facility at iThemba LABS will be ensured by setting up a primary standard for neutron measurements in the energy range from 30 MeV to 200 MeV. Furthermore, as an ISO-accredited facility, the fast neutron facility at iThemba LABS will be able to participate in international key-comparison studies in the area of neutron metrology for medium to high-energy neutrons. The key-comparison studies in the area of neutron metrology are organized by the Consultative Committee for Ionizing Radiation (CCRI) of the International Committee for Weights and Measures (CIPM).

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