Neutrons for the next decade and beyond

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Book of Abstracts

Contents

The LICORNE directional neutron source and its associated physics program 1

Neutron production in the 7Li(p,n) reaction in the energy range 17-80 MeV 1

New detection systems at U-120M cyclotron 1

Fast-neutron induced alpha-particle emission and the dark side of the alpha-particle optical potential 1

Design, characterization and commissioning of an atmospheric neutron beamline for the irradiation of microelectronics 2

Splicing EXFOR for the next decades and beyond 3

The IPPE experience on the use of digital radiation spectrometers in neutron experiments. 3

Neutron induced reactions studies in the 1-200 MeV energy range. 4

The New Collaboration of the JINR and the iThemba LABS for Cross-Section (n,xn) Reactions Measurements 4

High-precision measurement of the inelastic neutron scattering cross section of 19F at GELINA 5

The neutron production facility at the Lawrence Berkeley National Laboratory 6

The Eastern European Cooperation in Fast Neutrons and ADSS Related Research 6

Worldwide Comparability in Measurement 7

Nuclear data measurements at white and quasi-monoenergetic sources of high-energy neutrons. 7

Monte carlo simulations of the present vault 8

Neutron metrology at the National Physical Laboratory. 8

MicroMegas-based detectors for neutron-induced reactions 9

Prompt Fission Neutrons in Coincidence with Well-Defined Fission Fragments: A Dedicated Experiment 9

30 years of fast neutron beams at iThemba LABS: retrospective waypoints and future horizons 9

1

The LICORNE directional neutron source and its associated physics program

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The LICORNE neutron source is a high-flux, naturally directional fast neutron source operational at the ALTO facility of the IPN Orsay since 2013. Highlights from the current physics program (e.g. fission fragment spectroscopy) will be presented along with future possibilities to use neutrons as a important tool for fundamental and applied research

2

Neutron production in the 7Li(p,n) reaction in the energy range 17-80 MeV

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The experimental data on the neutron production were collected during several irradiation campaigns on the NPI Li target using TOF method to measure the number of the peak neutrons in the forward direction, while the number of produced 7Be nuclei was determined with the gamma-spectrometry. The ratio of the forward directed peak neutrons agrees well with the formula introduced by Uwamino and other experimental data. The fit of angular distributions was performed.

3

New detection systems at U-120M cyclotron

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Intensive, high energy neutron beams with energies up to 33 MeV are produced using cyclotron driven broad-spectrum and quasi-monoenergetic neutron generators at the NPI. The neutron beams are well characterized with the TOF and PRT measurements.
The detection system of the charged particles from the (n,cp) reactions and the system for the detection of direct and delayed gammas produced in the reaction with neutrons are being developed.

4

Fast-neutron induced alpha-particle emission and the dark side of the alpha-particle optical potential

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The interaction of alpha particles with nuclei as well as the related optical model potential (OMP) were of special interest from the earliest days of nuclear physics,. The widely-used phenomenological OMP parameters have been derived from the analysis of either elastic-scattering or alpha-induced reaction cross sections below the Coulomb barrier, and then used to describe also the alpha-particle emission from hot nuclei excited in nuclear reactions. However the later studies are subject of also other various assumptions and quantities. Thus, the alpha-particle OMP for the incident channel seems similar to the familiar side of the Moon which only is facing always the Earth, but for the alpha-emission it is like the dark side of the Moon. Moreover, there is a so-called alpha-potential mystery [1] of the account at once of both absorption and emission of low-energy alpha particles, of interest for nuclear astrophysics as well as nuclear technology.
Former search for new physics in potentials to describe nuclear de-excitation made use of the assumption that particle evaporation occurs from a transient nuclear stratosphere of the emitter nucleus, with a density being not yet relaxed to the density profile expected for complete equilibration. It may be reassessed within a microscopic double-folded OMP (e.g. [2] and Refs. therein), following suitable results obtained similarly for the incident. However, the question of a real difference between the OMPs which describe either alpha-particle elastic scattering and induced reactions [3] or emission from excited compound nuclei [4] could be answered only following definite conclusions concerning the incident channel. Actually, the better results provided by this potential [3] within a large-scale nuclear-data evaluation [5] led to its use as the default alpha-particle OMP within the latest version of the code TALYS [6].
On the other hand, the need to use or not use the same potential also for emitted alpha particles, as pointed out recently for several nuclei within Refs. [7,8], respectively, should make the object of further discussions. The (n,alpha) reactions are particularly considered in this respect due to their interest for nuclear technology. On the other hand, the related statistical model (SM) analysis depends critically on the accuracy of the rest of SM parameters. They could be provided only by independent data analysis as an additional challenge to this work.
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5

Design, characterization and commissioning of an atmospheric neutron beamline for the irradiation of microelectronics

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The construction of ChipIr, a new beamline at the ISIS neutron and muon source in the UK, has been motivated by the very limited availability of fast neutron facilities, particularly in Europe, for testing of microelectronics for industry.
The fast neutron spectrum is generated by the spallation interaction of the ISIS accelerator 800 MeV proton beam on a tungsten target. The design of the beamline has been optimized for Single Event Effect testing at the device-level, board-level and system-level, which require a beam of high and

uniform intensity over a selectable area from a few to hundreds of cm^2.
Characterization measurements of the beam flux, spectrum and uniformity are presented. The methods that have been used are neutron activation foils analysis, solid state detectors (silicon and diamond detectors), and single event upset monitors with reference electronics. These methods provide complementary information and pro and cons will be discussed.
After the commissioning, ChipIr has now been used for about a year by industry. An overview of the main applications of ChipIr will give emphasis to the need of a further increase of worldwide availability of fast neutron test facilities.

6

Splicing EXFOR for the next decades and beyond

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Considerable experience and know-how has been acquired on basic nuclear data since the dawn of the nuclear age, however some of this achievement has been selective with regard to purpose and application and done through fitting, profiling the underlying cross section with the essential and available at time experimental information usually contained in EXFOR [1]. The experiments it contains are numerous, were pioneering and founding – they shaped our actual knowledge and allowed the safe development of primarily fission applications. Through the NRDC network this experimental world-wide data library for neutron and charge particles induced reaction is updated regularly, circa 400 new entries per year. Such methodology, fit for the purpose it has been designed for, came at a price: a proper, correct physics understanding of the compensation, correlation at play throughout the complex evaluation and simulation processes was overlooked – the single application driven data requirement differed significantly from the needs of today multi-physics applications.

Tremendous progress in evaluation methodology, simulation capabilities, granularity, and completeness in terms of targets, surrounding media, particle and energy ranges has been achieved since then enabling more detailed and probing aspects of the underlying physic to be unearthed and revealed. Many more of the 42 basic quantities (cross-section, double/triple differential, multiplicity, product yields, gamma emission, resonance parameters, integral, reaction rate, etc..) stored in EXFOR can be routinely accessed and put to work in unison.

Since the turn of the century, advanced physics model, simulation probe has highlighted certain short-cuts taken and shortages in the process biased toward one aspect of the fission industry: criticality. Modern global physics model, that rely on EXFOR entries for profiling also allows extension, supplementation and enhancement of the basic nuclear data so necessary to the modern shielding and non-criticality applications: accelerator, fusion, medical, metrology. Physics models also allow us to go where no experiment could go, usually with uncertainty. Modern data analytics unearth new finding, correlation in support of the physic models.

A modern, clearly labelled, thoroughly checked, regularly updated, advantageously deployed EXFOR experimental database, fortified to cater for the applications that depend more of the fast range is in the making. This paper will introduce IAEA's driven activities in the area of nuclear data experimental mining and analytic in support of various applications and relying on recent/coming-up experiments.

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7

The IPPE experience on the use of digital radiation spectrometers in neutron experiments.

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At the IPPE over the past 20 years, digital methods are widely used to register neutrons and products of nuclear reactions caused by neutrons. This method is based on the fact that the signals taken from radiation detectors are converted to digital form. Further processing of these signals is performed using DSP methods. Using the example of ionization chambers with Frisch grid, organic scintillators, inorganic scintillators, proportional and corona neutron counters, it was shown that digital processing gives a much better result than analog one. This result is obtained because the digital approach allows studying all available information contained in the waveform. Digital signal processing methods were successfully implemented to study the yields of fission fragments of heavy nuclei, to study ternary nuclear fission, to study the (n, a) cross section of the reaction on solid and gaseous targets, for neutron spectrometry by the time-of-flight method.

8

Neutron induced reactions studies in the 1-200 MeV energy range.

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The neutron is a wonderful tool for numerous topics like fundamental research, material science, biology, nuclear technology…. Neutrons are used on a very wide energy range from neV up to the GeV region. The (1-200MeV) energy range is of prime interest because it plays a role in many applications like therapy, single event upsets, fission and fusion technology… All these applications require accurate evaluated nuclear data libraries based on measurements and reaction models. In this region many threshold reactions are possible like (n,n'g), (n,xn), (n,lcp) or multiple chances of fission. Several reaction mechanisms take place (direct reaction, pre-equilibrium process, fission…) and are not well reproduced by simulation codes. New accurate measurements are needed to improve nuclear data libraries and theoretical models.
Very few facilities around the world deliver neutrons beam up to 200 MeV and there is an opportunity for iThemba laboratory to upgrade its neutron facility. Indeed the proton beam accelerated by the cyclotron can produce quasi-mono-energetic neutrons as well as continuous energy spectra. Neutron flux and spectrum are not the only important parameters, the time structure, the experimental room size and design are also key characteristics for the realization of complex experiments. The use of gamma rays and neutron detectors for example requires very specific background characteristics. Some examples of studies which could be performed in the 1-200 MeV region will be presented. We will show how the iThemba facility could be complementary to the existing facilities and what could be its added value. The requested properties of the facility will be shown by taking example of facilities already running or under development.

10

The New Collaboration of the JINR and the iThemba LABS for Cross-Section (n,xn) Reactions Measurements

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In the recent years, scientific interest in the feasibility study of accelerator driven sub-critical systems (ADS) for transmutation of the long-lived components of radioactive wastes (RAW) is very high. ADS systems are a part of research on future reactor IVth generation. The high-energy neutrons are an ideal tool to induce fission in most transuranic isotopes. The cross-sections for nuclear reactions induced by neutrons below 30 MeV are generally considered to be reasonably well known. There is a lot of interest to measure cross-sections of neutron induced reactions in the low and high energy regions and improve nuclear models at incident energies below 30 MeV as well as above 30 MeV. We are proposing a new measuremnt programan for Y, Bi, Co, Au (n,xn) cross section. On the begining we propose experiments which requires various neutron energies; 56 MeV, 66 MeV, 100 MeV and 180 MeV.

11

High-precision measurement of the inelastic neutron scattering cross section of 19F at GELINA

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Fluorine is one of the most important materials in the molten salt reactor (MSR), one of the Generation IV reactor types. These designs use molten fluorides or chlorides as fuel mixtures or coolants. This type of reactor is under research and development in several countries worldwide, motivated by the fact that the MSRs have certain unique characteristics which offer a safer, more efficient and sustainable form of nuclear energy. Inelastic scattering is the main neutron energy-loss mechanism in a reactor; precise knowledge of the cross section over a large energy range is therefore very important. An experiment was performed at the GELINA neutron source of the European Commission's Joint Research Centre (JRC) in Geel, Belgium, to determine the gamma-ray production cross sections for 19F. The gamma rays were detected using the GAINS spectrometer, which consists of 12 high-purity germanium detectors. The neutron flux was monitored with a fission chamber containing 235U. The GAINS setup is located at GELINA flight path 3, 100-m measurement station, offering both an excellent neutron energy resolution in a time-of-flight measurement, and a relatively high neutron flux. Level cross sections and the total inelastic cross section are calculated from the measured gamma-production cross sections. Previous neutron inelastic scattering data on 19F suffer from poor neutron energy resolution and large gaps exist in the covered neutron energy range. The present experiment was the first one to measure the inelastic neutron scattering cross section of 19F with very good neutron energy resolution, low total experimental uncertainty (less than 5%), and over a large incident neutron energy range (from around 100 keV up to 15 MeV). As the lithium

fluoride scattering sample also contained 7Li, the experiment allowed the re-measurement of the 7Li 478-keV gamma-ray production cross section. This transition is intended to be used as a standard gamma-production cross section in the future, but some discrepancies exist between previous data sets.

12

The neutron production facility at the Lawrence Berkeley National Laboratory

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The Bay Area Neutron Group (BANG) has developed and characterized a high-intensity neutron source facility at the 88-Inch Cyclotron of the Lawrence Berkeley National Laboratory. A variety of white neutron sources have been produced via deuteron breakup on thick beryllium and tantalum targets with incident deuteron energies from 16-33 MeV. Neutron energy spectra are measured with activation foils and time-of-flight techniques. A flux of $\sim 10^7$ n/cm^2/s at 5 m from a beryllium breakup target is achieved with a 10 μA, 33 MeV deuteron beam. Efficient physical collimation of the breakup source allows for a closely-packed geometry of gamma ray detectors otherwise sensitive to neutron damage such as high-purity germanium.

Double-time-of-flight techniques are used to characterize scintillator response functions down to neutron energies (<100 keV) not previously feasible. Time-correlated single photon counting is used to characterize scintillator light decay over long time scales and high dynamic range. The facility is also used to measure cross sections for medical radioisotope production and to gauge equipment and materials damage response to neutron irradiation.

Furthermore, the facility has been recently funded to measure inelastic neutron scattering cross sections through the assembly of a Gamma-Energy Neutron-Energy Spectrometer for Inelastic Scattering (GENESIS). High-purity germanium detectors in coincidence with twelve or more neutron scintillators will detect characteristic gamma rays in coincidence with scattered neutrons to determine the $d\sigma_{inl}/dE_n dEn' d\Omega$ triple-differential inelastic cross section of up to 50 MeV neutrons for a wide variety of nuclei. Additional funding has recently been granted to use to measure short-lifetime independent fission fragment yields as well.

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13

The Eastern European Cooperation in Fast Neutrons and ADSS Related Research

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Wide fast neutron research cooperative network is being developed between the Czech Republic, Ukraine, Republic of Armenia, and Indian universities in last five years. All has begun in JINR Dubna, however, at the moment local facilities are used for the research. The point of cooperation were Accelerator Driven Subcritical Systems, and the medium to high energy nuclear data (cross-section, fission yields etc.) needs. At the moment we are focused on cross-section measurement at Indian facilities (3 to 20 MeV), at CANAM in Rez (20 – 45 MeV), with proposals to iThemba and RCNP (up to 400 MeV). We are preparing to use photonuclear accelerator driven neutron sources (Uzhorod's microtron & Yerevan's synchrotron) and spallation targets for validation experiments. Unfolding tools and variable neutron detection systems are also of our interest. We would like to contribute to the discussion of fast neutron facilities needs from ADSS community point-of-view.

14

Worldwide Comparability in Measurement

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Accurate, comparable measurement results depend on globally agreed units of measurement, the realisation of these "primary" units and the establishment of common references traceable to the primary units. The Metre Convention (Convention du Mètre) of 1875 is the basis for international agreement on units of measurement and created the International Bureau of Weights and Measures (BIPM), an intergovernmental organisation under the authority of the General Conference on Weights and Measures (CGPM) and the supervision of the International Committee for Weights and Measures (CIPM).

The CIPM Mutual Recognition Arrangement (CIPM MRA) is the framework through which National Metrology Institutes (NMIs) demonstrate the international equivalence of their measurement standards and the calibration and measurement certificates they issue.

Within this context the role of NMISA and iThemba LABS in creating a common reference for medium and high energy neutron measurements, is explained.

15

Nuclear data measurements at white and quasi-monoenergetic sources of high-energy neutrons.

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There is a clear and long-standing demand from the International Atomic Energy Agency (IAEA) to improve the situation of nuclear data, in particular reference cross sections, in the energy range

above 20 MeV. Spallation neutron sources, such as n_TOF at CERN, are the workhorses for such measurements because they provide a continuous energy coverage. However, they pose specific technical challenges for neutron measurements at high energies due to the presence of intense prompt photon bursts (�-flash), low duty cycle and high instantaneous event rates. This is why quasimonoenergetic sources such as the 7Li(p,n) facility at iThemba LABS are attractive for detector development and complementary experiments at selected neutron energies. As an example, the measurement of the 235U(n,f) cross section relative to the differential neutron-proton scattering cross section is discussed.

16

Monte carlo simulations of the present vault

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In order to perform measurements of high-energy neutron fields, it is necessary to calibrate instruments in reference fields at energies from 20 MeV up to an energy approaching 1 GeV.
The calibration of instrumentation for high-energy neutrons can be achieved in iThemba Laboratory for Accelerator-Based Sciences (TLABS) where a relatively high yield of quasi-monoenergetic neutrons up to 200 MeV can be produced via the 7Li(p,n) reaction.
However, several technical limitations of the neutron beam facility impair accurate measurements so that upgrading the facility is needed. The most important improvement necessary at the present neutron beam facility in vault D is the reduction of the neutron background.
This work aims at estimating the neutron background in different location of the present experimental area of iThemba Labs (i.e. vaultD) by simulating neutron transport with MCNPX for neutrons generated by irradiation of a lithium target with incident proton beams of 66 MeV and 200 MeV. The identification of the main neutron leakage paths will also be investigated. These results combined with measurements (planned in January 2019) of the neutron background in vaultD will provide a first step to a full set of recommendations for the upgrade of the facility.

17

Neutron metrology at the National Physical Laboratory.

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The National Physical Laboratory (NPL) is the UK's national standards laboratory. The Nuclear Metrology Group (NMG) operates world-leading facilities for measuring neutron source emission rates and providing extensive accelerator and source based calibration fields. Monoenergetic neutrons are produced via the interaction of ion beams from a 3.5 MV Van de Graaff accelerator with different neutron producing targets. Well characterised broad-spectrum fields are available from different radionuclide sources. Thermal fields are produced from a large graphite moderator containing two beryllium targets that produce neutrons copiously when irradiated with deuterons from the accelerator. Moreover, NPL has one of only a few facilities in the world capable measuring the neutron output rate from sealed radionuclide sources to high precision, thanks to the activation of a manganese sulphate solution. In addition to that, NPL can undertake on-site spectrometry measurements with a variety of different detectors. The current capabilities of the NPL neutron producing facility will be presented, and the ongoing research activities and future perspectives will be discussed.

18

MicroMegas-based detectors for neutron-induced reactions

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Micromegas detectors are versatile gaseous charged-particle detectors. They can be used for neutron detection with a suitable neutron/charged particle converter, usually Li-6, B-10 or U-235. The detector consists of a two-stage parallel-plate avalanche chamber with an ionization drift region and an amplification region. The use of the microbulk technique allows the use of printed circuit board techniques to produce a very thin, radiation resistant, and low-mass detector with an amplification gap of typically 50~micrometer. Micromegas neutron detectors have been used both at pulsed neutron time-of flight facitlies and at a continous neutron beams. An overview of MicroMegas detectors for neutron detection and neutron reaction cross section measurements and related results and developments will be presented.

19

Prompt Fission Neutrons in Coincidence with Well-Defined Fission Fragments: A Dedicated Experiment

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It is generally accepted that prompt fission neutrons (PFN) have two components with unknown relative intensities: neutrons dynamically released at scission (SN) and neutrons evaporated from fully accelerated fragments (EVN). There is no indication which of these two components is the dominant one since the gross features of PFN can be reproduced by both models [1, 2, 3]. To remove the ambiguity, instead of looking at averaged properties, one has to study PFN observables correlated with fragment properties.
It has been pointed out [2] that, for a fixed fragment-mass division, the kinetic energy spectrum and the angular distributions with respect to the fission axis of EVN and of SN are different: the first are smooth while the second present oscillations. In the case of angular distribution, the oscillations are due to the proximity of the fragments at the moment of emission. The calculated spectrum is not smooth since it consists of a finite weighted sum (only 35 non-negligible terms) of individual contributions with different mean values and widths.
To confirm or infirm experimentally the existence of fine structures in the angular and energy distributions of PFN is of outmost importance. It unveils the origin of the neutron emission during fission which is the best known and most discussed feature of nuclear fission.
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20

30 years of fast neutron beams at iThemba LABS: retrospective waypoints and future horizons

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The fast neutron facility at iThemba LABS is about to undergo a major upgrade with a respect to both its physical infrastructure and supporting instrumentation. The new vault will be designed to both serve a wider spectrum of users, as well as to meet the requirements to be recognised as a designated metrological facility for fast neutron beams between 30 and 200 MeV. Since its construction in the 1980s the facility has remained largely unchanged, but has featured a wide assortment of projects, both fundamental and applied. Vignettes from a selection of "waypoint" projects from the last 30 years will be presented, together with thoughts on the opportunities that the new facility will offer.