The Medley facilities past and future: Fast neutron nuclear data for science and industry

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The Medley facility has been installed at The Svedberg Laboratory (TSL) for more than 10 years. During that time double-differential cross-sections for neutron-induced light-ion production have been measured for a range of target nuclei at incoming neutron energies of up to 175 MeV. Now, Medley will move to a new home at the Neutrons For Science (NFS) facility at GANIL in France. This facility is currently under construction and should start operating 2014. The pulsed beam combined with time-of-flight measurements will allow for good neutron energy resolution. The paper briefly summarizes the motivation for the experiment, design concepts, results achieved at TSL, and the future plans at NFS.

Keywords: Nuclear data, Neutron-induced reactions, Light-ion production

1 Introduction

One of the tasks of applied nuclear physics is to provide nuclear data for applications. This is achieved by a joint effort of theorists and data evaluators that develop and improve nuclear models and computer codes, and experimental nuclear physics, delivering data such as cross-sections, angular distributions, fission fragment mass distributions, fission neutron multiplicities, etc., which evaluators try to describe and can be used as benchmarks. To make this process effective from the applications point of view, feedback from analysis of the impact of the data uncertainties on the application is needed.

Models are needed to interpolate but also extrapolate to regions where no measurement data are available. These models may rest on a microscopic physical understanding of the described process, but are, generally, phenomenological descriptions with the goal to consistently describe the experimental evidence.

A key task of evaluators is the handling of data uncertainties and correlations. While measurements always include uncertainties – they would be considered useless otherwise-nuclear data evaluations still do not, generally, include covariances. To overcome this difficult process and provide a rather elegant shortcut towards sensitivity studies of large scale systems and uncertainties of macroscopic parameters, the Total Monte Carlo (TMC) method was recently proposed. This method might well mark a revolution in nuclear data evaluation since it is systematic, reliable and reproducible. In terms of quality assurance for applications like fission reactors, these are all key factors. In the TMC method, the input parameters to the model code are varied in a random fashion and the resulting calculated data are then validated against the experimental data base (i.e. EXFOR) and, if approved, processed for usage in a Monte Carlo code describing the application and delivering of macroscopic parameters. Running this chain several hundred times delivers uncertainties and allows for sensitivity studies in a, at least in principle, straight forward way.

The success of the TMC method rests on a combination of state-of-the-art nuclear model codes that are easy to handle, high-quality experimental data, and sheer computer power. For the former, the Talys code is a good example. This code is easy to run, relatively fast, comprehensive, and, not the least, openly available.

High-quality experimental data are needed to constrain the calculated random evaluations and to introduce the correlations. Such data need to be obtained at, on the one hand, strategic points from the theory point-of-view, and, on the other hand, areas that are defined by the applications sensitivity.

2 Neutron Nuclear Data Needs

Experimental data on neutron-induced reactions are important for several applications. Critical fission reactors operating in either the thermal or fast domain, or sub-critical, accelerator-driven systems for
incineration of nuclear waste may serve as the probably most important examples. Other relevant applications are fast-neutron cancer therapy, dosimetry, and electronics applications, i.e., studies of single-event effects.

In the energy range below 20 MeV, a wealth of experimental data has been accumulated since the discovery of the neutron and nuclear fission about 75 years ago. This range is experimentally relatively easy to access, e.g. by using 2.2 or 14 MeV neutrons from neutron generators using the DD and DT reaction, respectively. Hence, rather reliable models are available in this domain.

Applications like those mentioned above, however, need data at much higher energies and the energy region between 20 and 200 MeV has been identified to be of crucial importance. This region is partly defined by the applications, but mostly from nuclear theory; at energies higher than 200 MeV, models like the intra-nuclear-cascade model are believed to work satisfactory. Therefore, this intermediate energy region, where different nuclear models meet, needs reliable data.

Experimental measurements in this energy region have, before the Medley measurements, mainly been performed at UC Davis\(^4\), USA, and Louvain-la-Neuve\(^3\), Belgium. However, the highest energy reached at these facilities is about 70 MeV.

3 Neutron Experiments in Uppsala

The Svedberg Laboratory (TSL) in Uppsala provided an excellent environment for extending the energy region where neutron-induced reaction data are available. Since the construction of the first neutron beam-line\(^6\) in the late 1980s, many experiments have been carried out to explore neutron reactions at energies up to 175 MeV. Two important examples are the SCANDAL experiment\(^7\), studying elastic neutron scattering\(^8\), and, more recently, even inelastic neutron scattering\(^9\), and the Medley set-up. The latter focused on light ion-production measurements\(^10\), but was also used for neutron spectrum measurements using elastic \(np\) scattering\(^11\), fission studies\(^12\), and even \(nd\) scattering for studies of three-body force effects\(^13\).

4 Medley Experiment

The set-up consists of a scattering chamber in which an arrangement of eight \(\Delta E-\Delta E\)-E detector telescopes is mounted on a rotating table. The telescopes are placed at different angles (in steps of 20 degrees), and the use of a thin (50-60 \(\mu\)m) silicon surface barrier detector (SSBD), a thick (400-1000 \(\mu\)m) SSBD, and finally a CsI (Tl) detector of sufficient length to stop particles even at the highest energy, allows for particle identification and measurement of double-differential cross-sections (ddx) over a wide dynamic range. The set-up is very flexible since the used SSBD detector thicknesses in each telescope can be adapted for the conditions in each campaign, and, in addition, distance and angle of the telescopes can be changed easily. Within an experimental campaign, each telescope is used at two different scattering angles allowing for cross-checks and ensuring redundancy.

The chamber is evacuated during an experimental run and up to three different target discs (typically with a 25 mm diameter and thickness of 500 \(\mu\)m) can be put into or removed from the beam without breaking the vacuum.

The lowest detectable particle energy is only limited by the SSBD detector noise. Depending on the particle identification needs, protons with energy down to about 0.5 MeV and alpha particles with energy down to about 4 MeV can be handled.

A first summary of the work done with Medley over the past 15 or so years has recently been given\(^14\). The original set-up, running mostly with a 96 MeV neutron beam, the revised set-up for the 175 MeV campaign, and the data analysis and data correction procedures are described elsewhere\(^15,16\).

5 Achievements so far

A large body of experimental data on neutron-induced light ion production at 96 MeV has been published over the years. Studied targets include carbon, oxygen, silicon, iron, lead and uranium\(^15\).

After construction of a new neutron beam line at TSL, an experimental campaign at 175 MeV could be conducted during the last years. This campaign is now finished but the analysis of these data from carbon, oxygen, silicon, iron, bismuth and uranium is still in progress. In the case of iron and bismuth data, the latest, so far still preliminary, status is found in the PhD thesis of Bevilacqua\(^17\).

As mentioned above, the experimental data are used for testing and improving nuclear model codes. Using, e.g., the Talys code, one can identify and study the relative importance of different reaction mechanisms. An example for this is the identification of a quite sizeable contribution from multiple pre-equilibrium emission\(^17\) to the measured cross-sections at 175 MeV. Furthermore, it was found that the contribution of the direct-like nucleon transfer for...
emission of composite particles in the pre-equilibrium process, as it is treated in Talys, is overestimated. Therefore, a refined systematics, which also improves the description of the proton energy spectra, was proposed\(^\text{17}\).

Here, a note on the neutron energy spectrum of the delivered beam is in place. The neutron beam is produced using the \(^{7}\)Li(p,n) reaction. This process yields a so-called quasi-monoenergetic neutron energy spectrum consisting of a peak from \(^{7}\)Li(p,n)\(^{7}\)Be reactions with about 40-50\% of the neutrons, and a tail at lower energies from break-up reactions.

Due to limited time-of-flight resolution, the neutron low-energy tail can only partly be suppressed. Hence, the obtained cross-section data are not strictly for a narrow neutron energy bin, but generally, include a contribution from the tail. In the case of the 96 MeV data, this tail is rather small and could have been correct for without introduction of too much bias. We nevertheless decided to publish the results as uncorrected for the tail contribution but publish also the accepted neutron energy spectrum.

This principle will be followed also in the 175 MeV cases where the neutron tail still presented in the accepted neutron spectrum is quite significant. In order to guarantee transparency we will publish the data as uncorrected for the neutron tail but also give the accepted neutron spectrum. In addition we will publish our “best guess” of true mono-energetic cross-sections, i.e. tail-corrected data. For this we intend to use renormalized Talys calculations, since Talys seems to produce reasonable shapes for the dx dx.

6 Future Ideas

During 2013, Medley will move to the new Neutrons For Science (NFS) facility at GANIL, France\(^\text{19}\). Currently NFS is under construction and first beam for commissioning runs are expected for 2014. This facility will, in the first stage, deliver white neutron beams from (p,n) or (d,n) reactions with energies\(^\text{19,20}\) up to about 35 MeV. The time structure of the beam – proton pulses will have a width of less than 1 ns and the time between subsequent pulses is 1.1 \(\mu\)s – will be well suited for usage of time-of-flight (TOF) techniques. We, therefore, intend to equip the Medley set-up with an arrangement of at least two parallel-plate avalanche counters (PPAC), one on each side of the neutron target, as shown in Fig. 1. The PPACs will deliver the needed TOF information for determination of the incoming neutron energy causing the current event.

Fig. 1 — Planned layout of the PPACs inside Medley. The target and the PPACs are tilted at an angle relative to the incoming neutron beam. Placement of two of the Medley telescopes is indicated.

Note that here, as was the cases also at TSL, neutron “beam” actually means about one neutron per pulse onto the Medley target.

One of the proposed experiments at NFS concerns measuring the \(^{238}\)U (n,fission) cross-section relative to elastic \(^{1}\)H (n,p) scattering. Both reactions are used as standard reference cross-section. The experimental aim is to link these two cross-sections together in the 6-34 MeV range. A sandwich target, as indicated in the Fig. 1, consisting of the fission target on one side and polyethylene on the other will be used.

With this design, it will be possible to reduce systematic uncertainties to a minimum. Since the measurements are carried out simultaneously, with PPAC sensitivity adjusted for scattered protons and emitted fission fragments, respectively, the targets will be exposed to the same neutron flux. The detector telescopes on either side are identical and can be interchanged. Last not least, the mass of the fission target can be determined from the \(\alpha\)-decay activity, measured with the same set-up\(^\text{12}\).

7 Conclusions

In the present paper, an overview of the motivation, basic design principles, experimental results, and future plans for the Medley experiment is given. The key achievement is that the energy range for available experimental data on neutron-induced light-ion production could be tripled, and high-quality experimental constraints for nuclear-reaction model development could be given. Turning now towards a lower energy range at the future NFS facility, Medley is expected, e.g., to give a substantial contribution to minimize uncertainties in neutron cross-section standards.
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