IAEA Technical Meeting on (alpha,n) nuclear data evaluation and data needs

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Virtual

Book of Abstracts

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(α, n) measurements at University of Notre Dame and AZURE2 R-matrix analyses

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Improved (α, n) cross section measurements are needed for a range of applications such as nuclear astrophysics, neutrino physics, geophysics, nuclear energy, and weapons research. While they are sometimes focused on different energy regions, all benefit from a improved measurements over a wide energy range. The connection is further strengthened through the use of R-matrix analysis for the evaluation of the data in all cases. The shared desire for an improved characterization of the cross sections makes it clear that a comprehensive R-matrix analysis will be the most consistent method, as opposed to piecemeal ones, that sample only a fraction of the data and energy range.

At the University of Notre Dame we have pursued an improvement (α, n) cross section evaluation both by making new experimental measurements and R-matrix analyses. In this talk I will give an overview of several (α, n) experimental projects that are planned or underway, with a focus on the ^{13}C$(\alpha, n)^{16}$O reaction. These new measurements focus on thin target, high energy resolution, differential measurements of partial cross sections using neutron and secondary γ-ray spectroscopy, the type of data most directly implemented into an R-matrix analysis. On the R-matrix side, I'll discuss efforts to construct an analysis of the ^{17}O system using the code AZURE2, and new methods of performing Bayesian uncertainty analysis to determine probability distributions for observables and to calculate covariance matrices for fit parameters.

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^{16}O(n,α_0)^{13}C Cross Section Normalization based on a new Time-of-Flight measurement using a Frisch Grid Ionisation Chamber.

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A ^{16}O(n,α)^{13}C reaction cross section measurement was carried out at the time-of-flight facility GELINA using a Frisch-grid ionization chamber built by HZDR. Between the reaction threshold (2.36 MeV) and a neutron energy of 9 MeV, ^{16}O(n,α_0)^{13}C events could be separated well from background events.
The experimental ^{16}O(n,α_0)^{13}C data are normalized relative to the neutron-induced fission cross section of ^{235}U of the neutron data standards using the H19 transfer instrument of PTB Braunschweig. Applying the principle of detailed balance, cross sections measured for the ^{13}C(α,n$_0$)^{16}O reaction (from Bair and Haas, Sekharan and Harissopulos)
above E$_\alpha$=1 MeV, are converted to ^{16}O(n,α_0)^{13}C cross section data and has been normalized to the cross-section integral over of the measured data from 4.0 to 5.3 MeV.
Evaluated ^{16}O(n,α)^{13}C data could be normalized as well.
An alternative normalization for the evaluated cross sections and ^{13}C(α,n)^{16}O data which is based on the ^{13}C(α,n$_0$)^{16}O thick target yield data of West and Sherwood is also presented and has an uncertainty of 8%. The data by West and Sherwood, used for this normalization are supported by two additional mutually consistent independent thick-target yield measurements.
The two sets of normalization factors agree within 3%.

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(α,n) cross section needs for fusion

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Monitoring and measurement of alpha particles produced in fusion deuterium-plasmas is an important requirement for the successful development of fusion power plants. The loss of fast (3.5 MeV) α-particles from the plasma is problematic; if too many escape without transferring their energy back into the plasma, then a self-sustaining system might not be achievable. During the development and testing of plasma operational scenarios, it is vital to have accurate measurement of the flux of fast-α losses.

Real-time measurement approaches based on liquid-scintillation are being developed, but these have uncertain tolerance to the harsh radiation fields in fusion reactors and, besides, also need characterisation. Robust measurements based on activation-foils are an obvious alternative and complementary technique. However, such an approach requires identification of suitable diagnostic foils with well-known, low uncertainty cross sections at 3.5 MeV. Most of the data is deficient (absent) at this energy, highlighting an urgent need to perform new measurements for relevant candidate materials.

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(a,n) reactions in low-background neutrino experiments

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Neutrons and gammas produced by alpha interactions with detector materials can hide the signal searched for in low-background neutrino experiments. Despite the high purity of the materials selected, alpha particles from the U and Th chain, and in particular from the decay of ^{222}Rn, such as ^{210}Po, can still have a high enough rate to produced a non-negligible amount of neutrons and gammas during the lifetime of the experiments. The combination of the prompt neutron signal with the delay capture can mimic the inverse-beta decay event, which is relevant for antineutrino analyses; or can fall in the region of interest for the neutrinoless double-decay searches. High energy gammas, produced by the de-excitation of the produced nuclei or emitted in the neutron capture reactions, can create a background for nucleon decay through invisible modes searches and for neutrino-electron scattering and neutrino-nucleus interactions. Furthermore, neutrons can be a potential source of background for supernova and solar neutrino studies. In this talk, the importance of a full understanding of the (α,n) and (α,nγ) reactions in the low-background neutrino field is presented.

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(alpha, n) Cross Section Data Improvement Needs for Next Generation Low-Background Neutrino and Dark Matter Experiments

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Next generation low-background neutrino experiments and generation-3 dark matter experiments will not only have to be located deep underground to shield cosmic induced backgrounds, but the sheer size of these next generation detectors can bring forth unprecedentedly large excavation costs. Therefore, it will be challenging to have an abundantly large passive and/or active shield around these large-sized detectors and cost effective solutions will have to be found. Crucial for such assessments is the accurate prediction of residual backgrounds that could enter the fiducial volumes of these detectors. Radiological neutrons from the surrounding rock and shot/concrete are hereby most critical, but also neutrons produced in the detector materials themselves, such as steel structures, insulating foam layers, internal cables, electronics components, etc. or the target material. It is relatively straightforward to assess neutron production yields from spontaneous fission of e.g. radiological U-238 concentrations in the rock or detector materials. But to date, it is still difficult to ascertain from U-238, Ra-226 and Th-232 concentrations the precise (alpha, n) production yields and neutron energy spectra that are induced by alpha-ray energies of up to about 9 MeV. These alpha-rays arise from alpha decays in the early and late U-238 decay chain, and the Th-232 decay chain, respectively. The uncertainties in the (alpha, n) production yields stem mostly from a lack of measurements and/or uncertainties in the existing measurements of (alpha, n) cross sections on many relevant target isotopes. More precise measurements of (alpha, n) cross sections in the alpha-ray energy range of up to 10 MeV on certain critical target isotopes would greatly mitigate the uncertainty on radiological neutron backgrounds for next generation neutrino and dark matter experiments and thus could in turn greatly help saving costs.

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(α,n) data for applications and detector simulation codes

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Knowledge on (α,Xn) reactions is required in several fields:

- Nuclear structure. Most of our actual experimental knowledge on (α,Xn) reactions comes from nuclear structure experiments between the 50's and the 70's. Nuclear technologies, non-proliferation and homeland security. α-emitters present in fresh/irradiated nuclear fuels can create a neutron source through (α-,Xn) reactions with (light) surrounding nuclei: fluorine, oxide and carbide fuels, vitrified nuclear waste$\cdots$
- Determination of the ^{235}U enrichment.
- Analysis of irradiated fuels, MOX fuels and fuels enriched in MA.
- Neutron background in underground experiments (nuclear astrophysics, Dark Matter) due to radiogenic α-decay chains.

We will present some examples of applications and the SaG4n tool, a GEANT4-based parser that allows to perform realistic simulations of (α,n) yields.

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(α,n) neutron yield calculations with NeuCBOT, the Neutron Calculator Based On TALYS

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NeuCBOT, the Neutron Calculator Based On TALYS, is a tool for calculating (α,n) neutron yields for arbitrary materials, given some activity of α-emitting contaminants. It combines stopping power calculations from SRIM with (α,n) cross section libraries calculated with TALYS to determine the neutron yield of materials with user-specified composition and contamination levels. Decay information for contaminants can be specified by the user, or they can be retrieved from their ENSDF files. NeuCBOT was created for the purpose of predicting (α,n) yields for materials used in low-background experiments, when experimental (α,n) cross sections are either unknown or highly uncertain; instead, NeuCBOT relies on TALYS's models. This talk will describe the NeuCBOT software, benchmark its performance, and discuss future plans and inputs that may improve its accuracy.

Session 3 / 17

A correction to the non-resonant process for elastic channels in R-matrix analysis

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I will propose a new method for describing the non-resonant process in the R-matrix theory, which is associated with additional background poles which are exclusively given to the incident particles. This method was applied to the simultaneous analysis of the 6Li(p,p0)6Li, 6Li(p,a0)3He, 3He(a,a0)3He and 3He(a,p0)6Li reaction cross-sections. It was found that the present approach was necessary to obtain a reasonable description of all the measured data simultaneously. I will also discuss the theoretical background for our recipe base on the physical aspects of the nuclear reactions, together with an outlook on the evaluation of 13C(a,n)16O cross sections.

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A new evaluation of 17O system (preliminary)

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A new evaluation of 17O system is made. The reaction channels includes:
'16O(N,N0)16O0 ' '16O(N,4HE)13C0 ' '16O(N,N1)16O1 '
'16O(N,N2)16O2 ' '16O(N,N3)16O3 ' '16O(N,N4)16O4 '
'16O(N,4HE1)13C1 ' '16O(N,4HE2)13C2 ' '16O(N,4HE3)13C3 '
'13C(4HE,4HE)13C0' '13C(4HE,N0)16O0 ' '13C(4HE,N1)16O1 '
'13C(4HE,N2)16O2 ' '13C(4HE,N3)16O3 ' '13C(4HE,N4)16O4 '
'13C(4HE,4HE)13C1' '13C(4HE,4HE)13C2' '13C(4HE,4HE)13C3',

and a reduced channel (used for 8 to 30 MeV), which represents the total contribution of other channels.
The energy range of experimental data is 1e-7 to 30 MeV. The fitting looks good. A full set of integral cross section evaluation values are given, which includes (n, tot), (n,el), (n, inl), (n, n1), (n, n2), (n, n3), (n, n4), and (α, n), (α, n0), (α, n1), (α, n2), (α, n3). Special attention is paid to the impact of new data on the evaluation. Boromiza (2020)'s new data on (n, INL) play a positive role of constraint and obvious improvement, Gazeeva（2020)'s new data on (α, n0) (180 degrees) is acceptable. In deBoer's new data, (α, γ6130) plays a positive role of constraint and significant improvement, and the differential cross section of (α, n0) plays a positive role of constraint and significant improvement. But, in Dr. deBoer's new data, the (α, γ6050) and all other data on (α, n1) are difficult to use.
Theoretically, the ground state of 16O is 0+, the first excited state (6050) is 0-, and the second excited state (6130) is 1.5-. So for gamma transitions, 0- to 0+ is forbidden, 1.5- to 0+ is open. So, (n, n2) is much larger than (n, n1), as the evaluation values in ENDF/B7 and RAC2015, and (α,n2) should be much larger than (α,n1), the (α, γ6130) should be larger than (α, γ6050), However, in deBoer's data, it's just the other way around, the (α, γ6050) is much larger than (α, γ6130), which requires careful study of the reasons why.

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Calculation of neutron production in (alpha,n) reactions with SOURCES4

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Sensitivity of underground experiments searching for rare events due to dark matter or neutrino interactions is often limited by the background caused by neutrons from spontaneous fission and (α, n) reactions from naturally occurring radioisotopes. A number of computer codes are available to calculate cross-sections of (α, n) reactions and neutron yields. We have used EMPIRE2.19/3.2.3 and TALYS1.9 codes to calculate neutron production cross-sections and show here a comparison of the results with experimental data. SOURCES4 is one of the tools to evaluate neutron production in different materials. We have updated the library of the modified SOURCES4A code to include the newly calculated cross-sections and recent experimental data. Neutron yields and energy spectra have been calculated using optimised cross-sections in SOURCES4A based on experimental data if available and reliable, complemented by calculations from one of the three models: EMPIRE2.19, EMPIRE3.2.3 or TALYS1.9. We present here the comparison of these neutron yield calculations with experimental data.

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Constraining (a,n) cross sections with indirect measurements

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The efficacy of the s-process in the production of heavy elements is influenced by a number of factors, including the number of neutrons available for neutron-capture reactions. Neutrons are produced by the ^{13}C$(\alpha, n)^{16}$O and ^{22}Ne$(\alpha, n)^{25}$Mg reactions, neutrons can be absorped by ^{16}O to make ^{17}O from which neutrons may be recycled through the ^{17}O$(\alpha, n)^{20}$Ne reaction or lost permanently through the ^{17}O$(\alpha, \gamma)^{21}$Ne reaction.

In this talk, the utility of indirect measurements in constraining (α, n) cross sections will be discussed, with particular focus on the ^{22}Ne$(\alpha, n)^{25}$Mg and ^{17}O$(\alpha, n)^{20}$Ne reactions and their application in s-process nucleosynthesis.

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Facilities, Measurements, and Experimental Verification of (α,n) for Dark Matter

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For many of the deep underground experiments searching for dark matter some of the most concerning neutron backgrounds come from the (α,n) process in the cavern or detector materials. Traditionally the focus of the dark matter community has been the calculation/simulation of the background based on (α,n) reaction evaluations and U/Th material assays. Dark matter working groups have been considering supplementing the evaluations with direct measurements either performed in new facilities or those already performed by our nuclear physics colleagues. I will describe the nuclei that are the focus of our dark matter/neutrino sub-working group on (α,n) and also how measurement facilities or other experimental verifications might be an enormous help on this problem.

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First LANSCE result on differential cross sections of the ^{16}O(n,α) reaction

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Oxygen is present in many materials - water, oxides, concrete and elsewhere - and the uncertainties in its nuclear data can have a significant impact on many nuclear applications. The current status of the oxygen-16 data is a 30-50 % discrepancy among various ^{16}O(n,α) and ^{13}C(α,n) cross section measurements. Reconciling these discrepancies and settling on a best value requires new measurements for confirmation.

We have performed the ^{16}O(n,α) reaction cross section measurement using the unmoderated white neutron source with the LENZ (Low Energy NZ-neutron induced charged particle detection) instrument at LANSCE. Double differential cross sections of ^{16}O(n,α_0) and ^{16}O(n,$\alpha_2 + \alpha_3$) at multiple angles are deduced from this work. The LENZ angular distributions are compared with previous measurements and evaluated cross section libraries. Using the newly developed LENZ postprocessing tool based on the MCNP's PTRAC output, experimental yields are compared with simulated yields using ENDF/B-VII.1 and ENDF/B-VIII.0. Within the experimental uncertainties, we report the 2017 LENZ cross sections with the angle-and energy-integrated ENDF/B-III.0 cross sections using the LENZ's response function. In addition, we will present the 2021 LENZ angular distributions with reduced systematic uncertainties, therefore to be directly used with other experimental data for the R-matrix analysis.

This work benefits from the LANSCE accelerator facility and is supported by the U.S. Department of Energy under contracts DE-AC52-06NA25396 and the U.S. Department of Energy under the Office of Experimental Sciences.

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HeBGB: the Ohio University Neutron Long Counter

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The 3HeBF3 Giant Barrel (HeBGB) detector is a neutron counter with nearly 4pi coverage and near-constant neutron detection efficiency that was purpose built to measure (alpha,n) reaction cross sections at the Edwards Accelerator Laboratory at Ohio University. This talk will describe the design, commissioning, and first science of HeBGB. Particular emphasis will be placed on recent results regarding the 13C(alpha,n)16O cross section at energies above 5MeV.

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Impact of (a,n) reactions on direct search of Dark Matter

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Accurate estimates of (a,n) neutron production rates, neutron energy spectra, and correlated gamma-rays are fundamental to understanding backgrounds in current and future rare-event studies. Neutrons are highly penetrating, and single scattering nuclear recoils produced by radiogenic neutrons can pose irreducible backgrounds to dark matter searches. Extensive and time consuming assay campaigns are necessary to measure the radiopurity of detector components and to identify low-background materials. In this talk, the problems posed by the (a,n) reactions in this field, the relevance of the (a,ng) process and the strategy for the calculation of this background are presented. The plans of the study group recently set up by several members of the dark matter and neutrino communities are also discussed.

Session 1 / 4

Low-energy cross section measurement of C13(a,n)O16

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The cross section of C13(a,n)O16 has recently been directly measured in the energy range 235 - 300 keV, for the first time reaching the astrophysical energy window of the s process for the generation of heavy isotopes. By measuring deep-underground at the Gran Sasso National Laboratory (LNGS), using clean He-3 counters and applying PSD techniques for the suppression of the intrinsic background the LUNA Collaboration has drastically improved the uncertainty of the available data.
A Monte Carlo R Matrix fit has been performed, extrapolating the cross section and generating a realistic uncertainty band.
The problem of normalisation of there various data sets has not been fully resolved and will be the main focus of upcoming measurements in a wider energy range at the new LUNA MV facility of the LNGS.
We present the completed low-energy measurement and give an outlook on the future high-energy campaign.

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Measurement of the cross section for the 13C(α,n)16O reaction and determination of the cross section for the 16O(n,α)13C reaction

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The angular dependence of the differential cross-sections for the 13C(α,n0)16O reaction was measured in the energy range of 2.0-6.2 MeV using the time-of-flight method for separating neutrons corresponding to the ground state of the residual nucleus. The integrated total cross-sections were derived from the measured data and the cross-sections for the 16O(n,α0)13C reaction were determined using the reciprocity theorem. The cross-sections obtained for the reaction 16O(n,α0)13C support the evaluation given in the ENDF/B-VIII.0 library.

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Preliminary analysis of 9Be(alpha,n)12C integrated and angular experimental differential data at below 4MeV

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This presentation intends to review a preliminary analysis of 9Be(alpha,n)12C integrated and angular experimental differential data at below 4MeV energy performed at CEA Cadarache using the SAMMY code. Although not up to date, we plan to extend this action in a near future using the CONRAD CEA code. During this work, a consistent set of Reich-Moore resonance parameters, including possible new resonances and reproducing the various 9Be(alpha,n) experimental data available, has been evaluated up to 4 MeV. A set of pointwise integrated and angular differential cross section data has been produced and its impact is tested using the recently developed iSourceC code (Intrinsic neutron Source computing code by Cadarache) for a homogeneous Pu9Be neutron source. The iSourceC tool is designed to test next evaluated files generation of angular resonant cross sections charged alpha-particles against experimental data when there are available. Among possibilities is the treatment of incident photons neutron sources.

Session 4 / 23

R-matrix evaluations of (alpha,n)

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A brief overview of the R-matrix evaluation method implemented in EDAf90 that emphasizes the relativistic model parametrization, polarization capabilities, and computational capabilities. We will review existing evaluations for (alpha,n) on material targets n, 1H, 2H, 3H, 3He, 6Li, 7Li, 11B (time permitting) and discuss recent activity on 13C in the 17O system analysis.

Session 2 / 16

Recommendations from an (α,n) Nuclear Data Scoping Study

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Neutrons and gamma rays emitted from the (α,n) reaction are an important component of nondestructive assay techniques used in safeguards to determine enriched uranium and other actinide inventories within the nuclear fuel cycle. Uncertainties in the reaction cross section, total neutron yield, neutron spectrum, and gamma spectrum from these reactions can negatively impact the determination of the mass of actinides of interest and can represent several significant quantities in unaccounted material over time. Recently, the Office of Defense Nuclear Nonproliferation, Research and Development funded a scoping study to understand the impact of (α,n) reaction data to the nonproliferation mission. The scoping study examined the current state of the nuclear data, and the limitations of the current codes used to predict the (α,n) neutron and gamma source terms. A particular focus was placed on nuclear data important to the assay of UF₆ cylinders. The nuclear data needs were prioritized, and recommendations made for new measurements, nuclear data evaluations and code development.

Session 2 / 7

TENDL-2021 library for (alpha,n) cross sections

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TENDL-2021 library for (alpha,n) cross sections
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The next version of the TALYS Evaluated Nuclear Data Library, TENDL-2021, contains an improved overall description of (alpha,n) cross sections and other reaction channels over the whole nuclide range. While for the important light nuclides the detailed resonance structure is obviously missing from the statistical model calculations, it is shown that TALYS generally provides a reasonable description of the excitation function, generally within 30%. For alpha-induced reactions, particular models for the optical model potential, level density and pre-equilibrium reactions are chosen. As production into ENDF and GNDS format has been automated, TENDL-2021 is particularly useful for general application in nuclear technology.

Session 2 / 20

The MANY project: measurement of neutron yields and spectra from (α,n) reactions in Spain

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Neutron production through α-induced nuclear reactions is relevant in several fields. Specifically, (α,n) reactions are interesting in nuclear astrophysics as a source of neutrons for the slow neutron capture nucleosynthesis (the s-process) [TAI16] and in the α-particle capture process (the so-called α-process) [WOO92, BLI17]. Other fields of interest include the neutron-induced background in underground laboratories [BET10], which is a crucial issue in low counting rate experiments, and in nuclear facilities such as nuclear reactors and particle accelerators [MUR02]. The data available in the EXFOR database [EXFOR] show large discrepancies with respect to the reported uncertainties. On the other hand, the single existing evaluated nuclear data library JENDL/AN-2005 [MUR06] contains information only for 17 isotopes. The general purpose and model driven TENDL [KON12] library provides data for a much larger set of isotopes, but it differs significantly from the JENDL/AN-2005 evaluation and the experimental data in several cases.
The MANY (Measurement of Alpha Neutron Yields and spectra) collaboration is a coordinated effort by Spanish research groups with the aim to carry out measurements of (α,xn) reactions. The MANY project relies on the use of α-beams produced by the two accelerator facilities CMAM [RED21] and CNA HiSPANoS [GOM21], and the scientific exploitation of complementary neutron detection systems: a 4π neutron counter with nearly flat response up to 10 MeV, based on 3He proportional counters moderated in a modular high-density polyethylene matrix, miniBELEN [MON20], and a second detector based on BC501/EJ301 liquid scintillator modules, MONSTER [GAR12, MAR14], which can operate as a time of flight spectrometer. Both systems are also complemented by γ-spectroscopy measurements for (α,nγ) reactions using an array of fast LaBr3(Ce) scintillator detectors of the FATIMA type [VED17] with angular resolution capabilities. All instruments are coupled to high performance digital electronics. The commissioning of the beam-lines with well-know (α,n) reactions is currently on-going. In this contribution an overview of the MANY project will be presented. The status of the commissioning and preliminary results will also be discussed.

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