Summary:Technical Meeting on (alpha,n) data evaluation and data needs

8-12 November 2021, Virtual

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Technical Meeting on (alpha,n) data evaluation and data needs, 8-12 Nov 2021

Goals:

- Review status of measurements, models and evaluations and ongoing projects
- Identify data needs: measurements, model and code development, and evaluations
- Compile list of priorities
- Recommendations to IAEA

Technical Meeting on (alpha,n) data evaluation and data needs, 8-12 Nov 2021, cont'd

- Participants: registered 61
- Countries: Austria, Belgium (EU), China, France, Germany, Greece, Italy, Japan, Portugal, Russia, Spain, UK, USA
- Applications: low-background rare-event experiments, nuclear astrophysics, fusion, nonproliferation, reactor applications

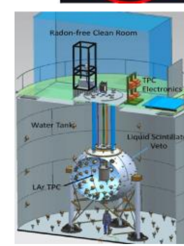
Applications I

- Low-background rare-event experiments:
  - Neutrino experiments: reactor- and geo-antineutrinos, neutrinoless ββ-decay, CP violation, solar neutrinos, SNe neutrinos, Exotic physics)
  - Dark Matter (WIMPs): low-energy nuclear recoils (10s keV)

    DAMA (LNGS), ANAIS (LSC), COSINE (Yangyang), SuperCDMS (SNOLAB), CRESST (LNGS), DarkSide, XENON (LNGS), LZ (SURF), nEXO, PICO, SNO+

    (alpha,n) WG: Snowmass2021 – LOI, White Paper

  - Nuclear Astrophysics: s process neutron source 13C(alpha,n), T~90 MK, E = 140-230 keV



Applications I cont'd

- Signal vs background competition:
  - β,γ: shielding+discrimination
  - Muons: underground+veto
  - production of neutrons (mimic ν's, WIMPs…):
    - external sources (cosmogenic, rock, distant materials): passive+active shielding !!! *Not valid for huge caverns in experiments like Dune*
    - Detector materials:
      - spont. Fission (high-Z materials),
      - *(alpha,n)* (**low-Z materials**)
    - alpha sources: **U & Th chains** in target material, detector structure, Rn emanation and ingress, ^{210}Po

Typical elements

- **detector material**→ require accurate cross sections (<9 MeV) and neutron spectra (stopping powers 2^{nd} order effect)
  - Acrylic: C, O
  - Teflon: C, F
  - PCB: C, N, O
  - Water: O (17O and 18O)
  - Resistors: Al, N, B (+Si, Mg…)
  - Mechanical parts: Cu, Ti, Stainless Steel
  - Wires: Be
  - Target: Ar, Xe, Ge, Li
- **Rock/shotcrete**: next generation (e.g. Dune)
  - O, Si, H, Al, Mg, K, Fe, Na, Ca

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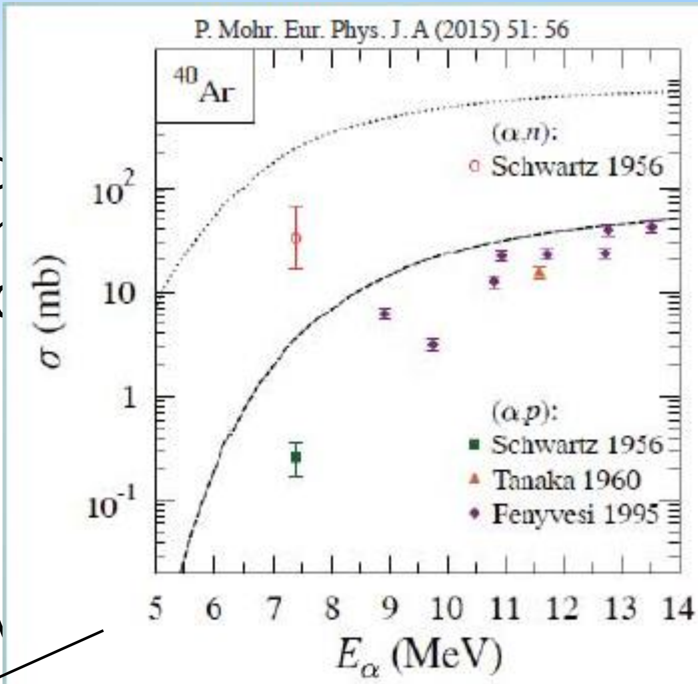
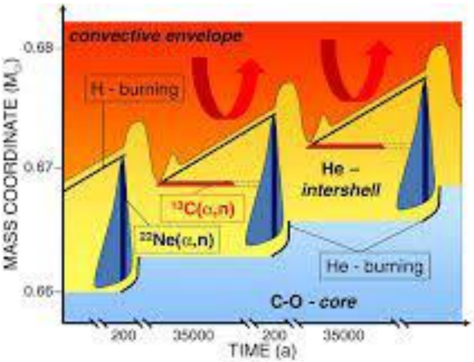
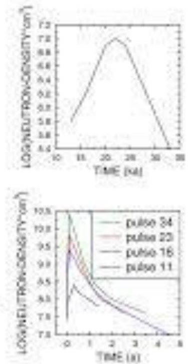


- **Rock/shotcrete**: next generation (e.g. Dune)
  - O, Si, H, Al, Mg, K, Fe, Na, Ca

Applications II

- Nuclear Astrophysics (***s process***, weak r-process, alpha process/I process)
  - Accurate knowledge of neutron source reaction rates down to very low energies (100s keV) - reaction networks –abundances
  - R-matrix fits – extrapolation to low energies (Gamow window): need to know resonances (Jpi): non-selective reactions





Typical reactions (s process):
^{13}C(alpha,n)
LUNA (GS), Notre Dame, Ohio U

^{22}Ne(alpha,n), ^{22}Ne(alpha,γ)
indirect: nTOF, TAMU, etc

^{17}O(alpha,n), ^{17}O(alpha,γ)
Notre Dame, DRAGON/TRIUMF

Applications III

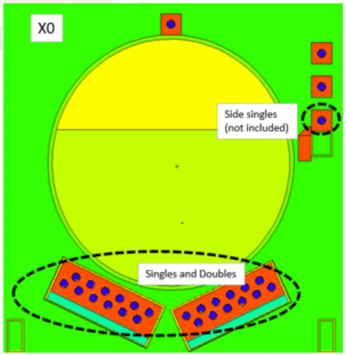
- Fusion (accurate accounting of alpha-losses – require alpha monitoring and measurements)
  - Aneutronics: real-time and per-pulse measurements (FILD, GRAM)
  - **Activation foil approach** (complementary): γ-signal vs n-induced γ's
    - Scoping study: Bonheure et al., Fus. Des. 88 (2013) 533
  - alpha-library needed in absence of data
  - Measurements to validate: ~1-3.5 MeV
  - Validation via 14 MeV neutron and 3.5 MeV alpha experiments

For D–T alphas	Thresholds (MeV)
$^{10}B(\alpha,n)^{13}N$	–
$^{14}N(\alpha,g)^{18}F$	–
$^{19}F(\alpha,n)^{22}Na$	2.4
$^{25}Mg(\alpha,p)^{28}Al$	1.4
$^{40}Ca(\alpha,p)^{43}Sc$	3.9
$^{41}K(\alpha,n)^{44}Sc$	3.7
$^{41}Ca(\alpha,p)^{44}Sc$	2.4
$^{43}Ca(\alpha,p)^{46}Sc$	1.7
$^{44}Ca(\alpha,p)^{47}Sc$	2.2
$^{45}Ca(\alpha,p)^{48}Sc$	1.3
$^{45}Sc(\alpha,n)^{48}V$	2.4
$^{46}Ca(\alpha,p)^{49}Sc$	1.6
$^{48}Ti(\alpha,n)^{51}Cr$	2.9
$^{51}V(\alpha,n)^{54}Mn$	2.4
$^{53}Cr(\alpha,p)^{56}Mn$	3.5
$^{55}Mn(\alpha,n)^{58}Co$	3.8
$^{76}Ge(\alpha,n)^{79m}Se$	3.1

Applications IV

- Nonproliferation (UF6 enrichment, spent fuel safeguards, passive NDA, neutron source characterization)
  - Recommendations from an (alpha,n) Nuclear Data Scoping Study (presented by C. Romano)
  - Priorities (cross-cutting):
    - SOURCES4C code modernization
    - Evaluation of F, O, C (alpha,n)
    - F thick target integral and activation experiments; n, γ spectra measurements; thin target energy-differential cross-section measurements
    - ENDF database modernization, GNDS format
    - Processing code updates

Passive Neutron Enrichment Meter (PNEM)



D.P. Broughton, S. Croft, C. Romano, A. Favalli, "Sensitivity of the simulations of passive neutron emission from UF_6 cylinder to the un in both $^{19}F(\alpha,n)$ energy spectrum and thick target yield of ^{234}U in UF_6 United States. https://doi.org/10.1016/j.nima.2021.165485

Strong overlap with all other application needs

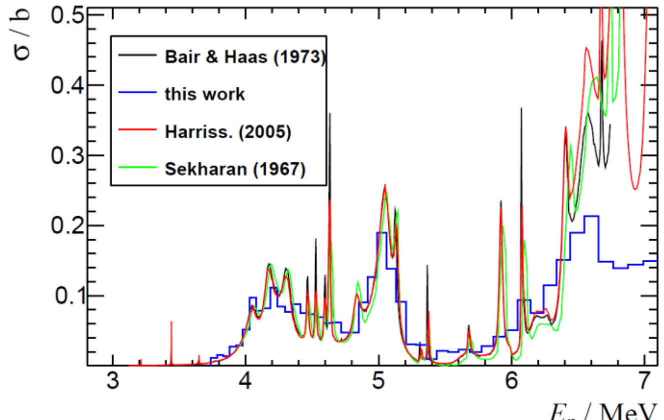
Applications V

- Reactor operations and safeguards (core calculations, neutron leakage, etc)
  - Dedicated session: ^{17}O system ($n+^{16}O$)
    - New evaluation of ^{17}O (Chen-Tsinghua Univ.)
    - Ongoing evaluation of ^{17}O (LANL)
    - New measurements: $^{16}O(n,alpha_0)$ (GELINA) (2.35-9 MeV)-renormalization of all data (4.0-5.3 MeV – below inelastic threshold) – above 5 MeV renormalization to West&Sherwood TTY
    - New measurements: $^{13}C(alpha,n_{tot})$ (Ohio U); $^{13}C(alpha,n_{1,2})$ (Notre Dame); $^{13}C(alpha,n_0)$ (IPPE)

S. Urlass (GELINA):

Cross section renormalization of $^{13}C(\alpha,n)$ data

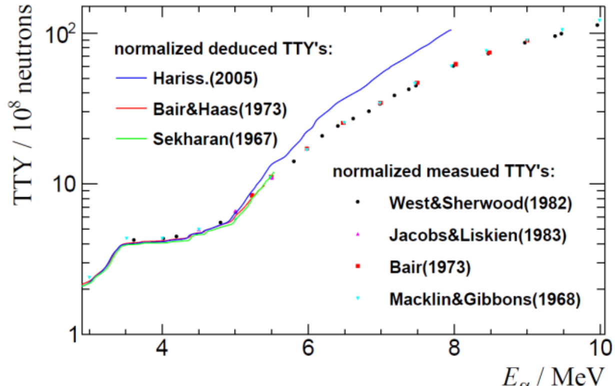
- using detailed balance to transform $^{13}C(\alpha,n)$ to $^{16}O(n,\alpha)$ data
- normalization region between 4.0-5.3MeV



$0.87 \cdot$ Bair & Haas , $1.30 \cdot$ Harissopoulos, $1.37 \cdot$ Sekharan

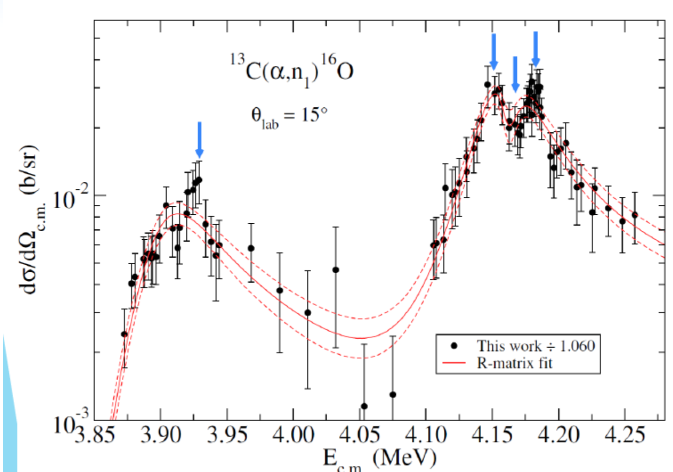
$^{13}C(\alpha,n)$ cross section normalization to thick target yield

- normalization between 3.5-5MeV to West & Sherwood's TTY
- below 5MeV: $^{13}C(\alpha,n)$=$^{13}C(\alpha,n_0)$

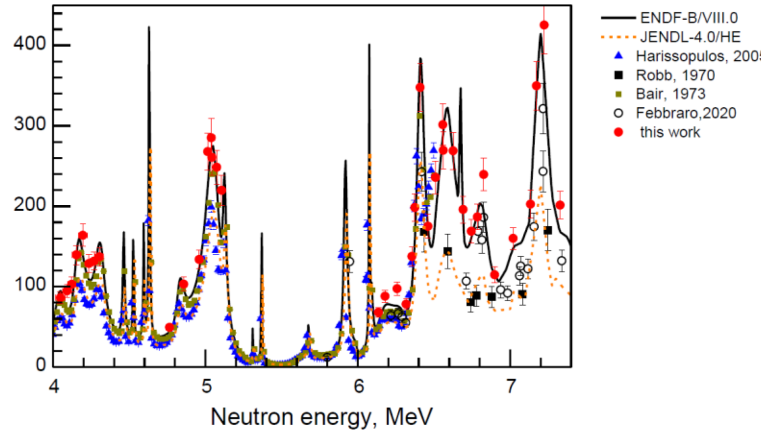


$0.85 \cdot$ Bair & Haas , $1.27 \cdot$ Harissopoulos, $1.35 \cdot$ Sekharan

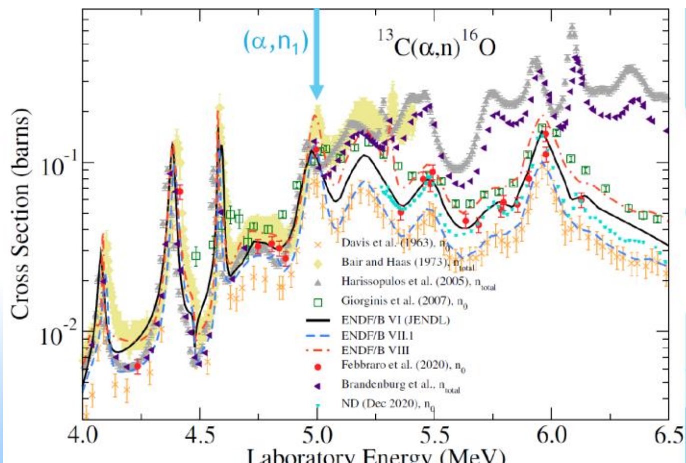
First ^{13}C(alpha,n1) measurement (DeBoer et al, ND)



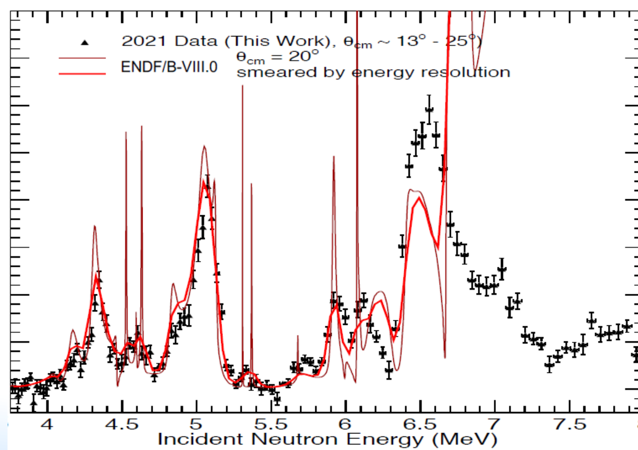
Results for ^{16}O(n,alpha$_0$) from ^{13}C(alpha,n$_0$) measurement (Prusachenko et al, IPPE)



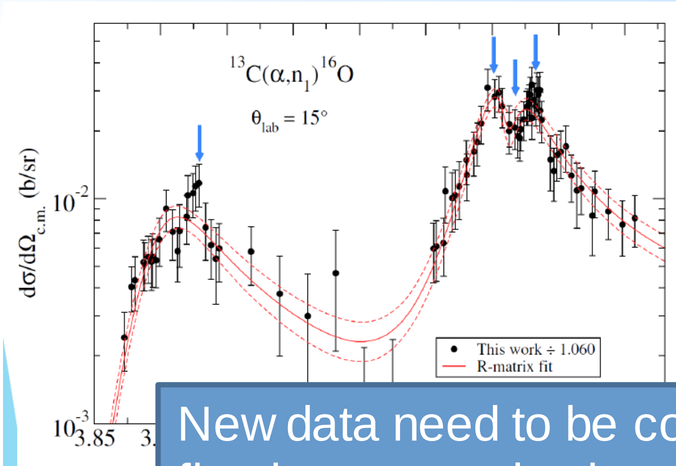
New ^{13}C(alpha,ntot) measurement (Brandenburg et al, OU) and 13C(alpha,n0) ang. Dist (OdeSA, ND)



Results for ^{16}O(n,alpha$_0$) from LENZ 2021 measurement (Lee, Kuvin, et al, LANL)



First $^{13}C(\alpha,n_1)$ measurement (DeBoer et al, ND)



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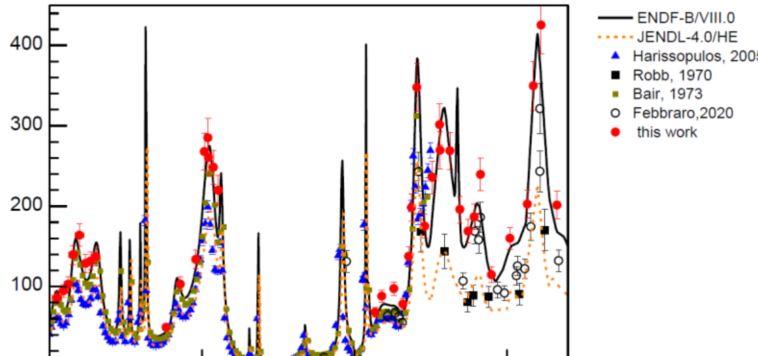
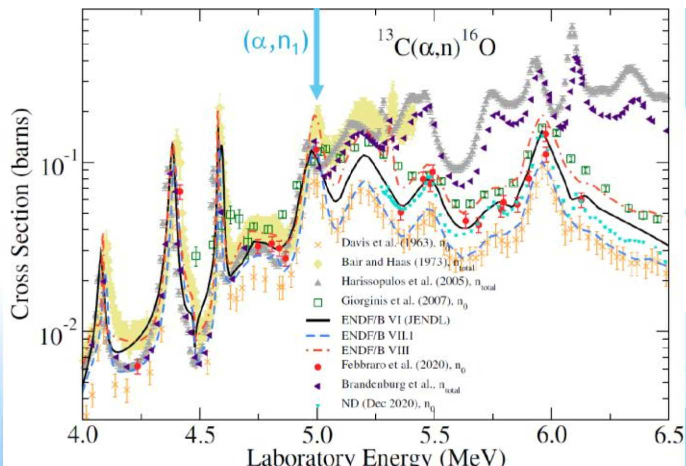
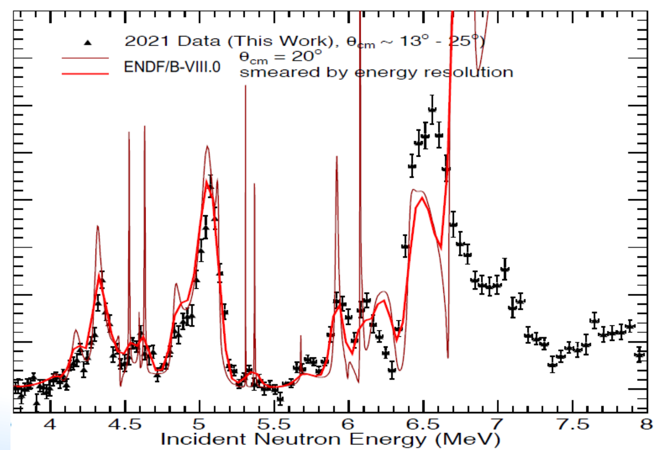


New data need to be considered – normalizations fixed – new evaluations up to 8 MeV

New ^{13}C(alph... OU) and 13C(alpha,n0) ang. Dist (OdeSA, ND)



measurement (Lee, Kuvin, et al, LANL)



Evaluations, Application codes

- New 17O (Tsinghua Univ.) and alpha+9Be (CEA-Cadarache) evaluations

- Application codes:
  - SOURCES4A (Univ. Sheffield)
  - NEUCBOT (Princeton)
  - SAG4N (CIEMAT)

(alpha,n) data needs

- Measurements: thin-target differential cross section measurements (total and partial), ang. distributions, neutron and gamma spectrum, reference data for rel. measurements (exhaustive and top priority tables)

In preparation: *Tables of priority measurements incl. required precision*

- Models:
  - A<20: extension of standard R-matrix codes to deal with increasing # of channels incl. breakup (reduced R-matrix, Faddeev-based or Hyperspherical approach for BU)
  - A>20: recommended Hauser-Feshbach ingredients; n-gamma correlations
- Evaluations: updated (alpha,n) evaluated libraries not limited to a few isotopes, including cross sections to excited states (partial)
- Application codes: SOURCES4C (orphan)/4A, NEUCBOT, SAG4N will benefit from improved evaluated (alpha,n) libraries

Table of priorities in (alpha,n) data measurements

Isotope	Reactor operation/safeguards		Nonproliferation, waste management		Low-background experiments (rare event detection)		Nuclear astrophysics		Fusion	
	Energy& resolution	Type of data	Energy& resolution	Type of data	Energy& resolution	Type of data	Energy& resolution	Type of data	Energy& resolution	Type of data
9Be			>4 MeV,	xs (tot,part,angdis)						
13C	**<9 MeV**	**xs (tot,part, angdis)**	**1-4 MeV,** **>5 MeV**	**xs (tot)** **xs (tot,part)**	**1-9 MeV, 10-20%**	**xs (tot, part, n-gamma correl., n,gamma spectra)**	**As low as possible, probably towards 100 keV**	xs		
17O			**<8 MeV**	**xs (tot,part)**			>1 MeV for TNSe	xs		
18O			**<8 MeV**	**xs (tot,part)**	0.5-9 MeV, 20-30%	xs (tot, part)	>1 MeV for TNSe	xs		
19F			**<9 MeV**	**Tot,part,angdis,n spect, tty**	**<9 MeV**	**xs(tot, part)**			Potential candidate	
40Ar					**<9 MeV**	**xs (tot)**				

International Nuclear Data Evaluation Network on Light Elements (INDEN-LE)

- Light Elements (INDEN-LE):

Improving evaluated nuclear reaction data on light-elements for energy and non-energy applications

  - Charged-particles

    Intercomparison of R-matrix codes, extension of R-matrix theory to treat increasing # of open channels, break-up channels, evaluation methodology, *(alpha,n) reactions*

  - Neutrons

    Evaluation of n+^{9}Be, n+^{14,15}N, *n+^{16}O*, n+^{23}Na

- *(alpha,n) reactions*
  - Evaluation of n+^{16}O incl. ^{13}C(alpha,n)
  - Evaluation of ^{19}F(alpha,n)
  - Evaluation of alpha+^{17,18}O

  https://www-nds.iaea.org/index-meeting-crp/CM-INDEN-LE/

Perspectives

- Meeting report published – INDC(NDS)-0836
- Follow-up activities on specific topics (reference reactions/monitor beams/targetry, HF calculations, evaluations for priority nuclides)
- Collaboration with international and national efforts:
  - (alpha,n) particle-physics Working Group (Snowmass LOI - White Paper)
  - MANY experimental campaign (Spain: Madrid, Seville; BELEn, MONSTER n detectors)
  - US university groups -> underground (LUNA, SURF)

IAEA
International Atomic Energy Agency
Atoms for Peace and Development

Thank you!