Nuclear Science with a C$^7$LYC Array

Partha Chowdhury
University of Massachusetts Lowell

Work supported by U.S. Department of Energy
NNSA-SSAA Grant # DE-NA0001988 (2013-2016)
A Versatile Gamma and Fast Neutron Spectrometer
C.J. Lister (PI), P. Chowdhury (co-PI)

*Evaluate a new bright dual n-\(\gamma\) scintillator, \(\text{Cs}_2\text{LiYCl}_6\), with excellent pulse shape discrimination, investigate its response to fast neutrons, and construct and characterize a Small CLYC Array for Neutron Spectroscopy (SCANS)*

NNSA-SSAA Grant # DE-NA0002932 (2016-2019)
Nuclear Science with a \(C^7\)LYC Array (SCANS)
P. Chowdhury (PI), C.J. Lister (co-PI)

*Explore the science potential of a 16-element \(^6\text{Li}\)-depleted (\(C^7\)LYC) array through targeted measurements in low energy nuclear science relevant to Stockpile Stewardship*


• 3 refereed publications
• 7 invited talks
• 4 posters
• 1 M.S. thesis

National Lab Collaborations
LANL, NRL, NSCL, ANL

Chowdhury NNSA-SSAP Symposium Albuquerque Feb 20, 2019
UMass Lowell CLYC-ers

Undergraduate
Michael D’Eon*
Joseph Dopfer*

Graduate
Tristan Brown*
Emery Doucet*
Nathan D’Olympia*
Emily Jackson
Patrick Copp

Post-docs
A.J. Mitchell
Gemma Wilson*
Chris Morse*
Edward Lamere*

Faculty
Partha Chowdhury (PI)*
Kim Lister (co-PI)*
Andrew Rogers
Peter Bender

* received direct support from NNSA grant
CLYC-ers: UML grad students/postdocs

Tristan Brown
- BS (2016)
- LANL intern (2016)
- MS (2018)
- UML PhD student

Gemma Wilson
- Post-doc (2015-17)
- Currently post-doc at LSU/ANL

A.J. Mitchell
- Post-doc (2013-15)
- Currently research fellow ANU, Canberra

Emery Doucet
- BS (2016)
- NEUP scholar (2015)
- UML PhD student

Chris Morse
- Post-doc (2015-18)
- Currently postdoc at LBNL

Edward Lamere
- Post-doc (Mar 2018 - present)

Patrick Copp
- PhD (2018)
- DOE SCGSR scholar (2016)
- Currently postdoc at ANL

Emily Jackson
- Ph.D. 2015
- Post-doc NRL (2015-17)
- Currently Scientist at Andrews AFB

Nathan D’Olympia
- Ph.D. 2014
- Currently Senior Scientist, Passport Systems

Chowdhury
- NNSA-SSAP Symposium
- Albuquerque
- Feb 20, 2019

Learning with Purpose
dual n-γ scintillator $\text{Cs}_2\text{LiYCl}_6$ (CLYC): prehistory

- $\gamma$ resolution better than NaI
- $< 5\%$ $^{137}\text{Cs}$

DOE-SBIR industry grant with RMD Inc.

excellent n-γ PSD

Fast neutron response via $^{35}\text{Cl}(n,p)^{35}\text{S}$, $Q=+615$ keV

Thermal neutron response via $^6\text{Li}(n,\alpha)t$, $Q = +4.8$ MeV

D’Olympia et al., NIM A694, 140 (2012); NIM A714, 121 (2013); NIM A763, 433 (2014)
SCANS : Small C⁷LYC Array for Neutron Spectroscopy

- Eliminate $^6$Li(n,α) thermal peak via $^7$Li-enriched C⁷LYC
- Explore fast neutron spectroscopy potential
- A 16-element array of 1” x 1” C⁷LYC (largest crystals available at the time)

- ~10% neutron pulse height resolution!!
- No long ToF arm needed
- close placement allows increased geometrical efficiency

- Nuclear science with SCANS (C⁷LYC)
- Larger (3” x 3”) crystal (acquire and characterize)
- Elastic/inelastic neutron scattering at Los Alamos
- Beta-delayed neutron spectroscopy at CARIBU (ANL) and NSCL
- Efficiency and low energy measurements at UML
56Fe(n,n') SCANS at LANSCE

- 800 MeV pulsed protons on W spallation target
- 20 m flight path to scattering target (Fe)
- C7LYC detectors 17 cm from target
- TOF to detector provides incident energy
- Pulse height in C7LYC provides scattered energy
$^{56}\text{Fe}(n,n')$ SCANS at LANSCE
$^{56}\text{Fe}(n,n')$ SCANS at LANSCE
$^{56}\text{Fe}(n,n')$ SCANS at LANSCE

$^{56}\text{Fe}(n,n')$

$E_n = 2.5$ MeV

Cross Section (mb/sr)

Angle (Degrees)

Machine learning algorithms capable of separating neutrons and gamma-rays in CLYC scintillators in the energy range investigated

CLYC – intrinsic activity

3"x3" C⁷LYC
10-hrs
0.4 alphas/s

Actinide contaminants
Different material batches different
Neutron activation under study
Eventual need to specify impurity tolerances

Efficiency estimates & $^{35}$Cl(n,p) cross-sections

MCNPX

ENDF/B-VII.0 (2006)

ENDF/B-VII.1 (2011)
35Cl(n,p) cross-sections

A measurement of the 35Cl(n,p) cross section in the MeV region


Proposal to directly measure the 35Cl(n,p) reaction cross section with the LENZ array of Si detectors (experiment performed in January 2018, under analysis)

12C(n,n’) data from first LANL experiment with C7LYC array

Resonances in incident neutron energies measured via TOF
Reflects structure in 35Cl(n,p) cross-sections
UMass Lowell Radiation Laboratory: Facilities

1 MW research reactor

- open pool;
- LEU fuel;
- 3 horizontal beam ports;
- in-core sample location (~10^{13} n/cm^2/s);
- graphite thermal column (~10^6 n/cm^2/s);
- digital neutron radiography
- hot cell with remote manipulators
- 100 kCi 60Co source for gamma irradiation

p, d, He ions;
100 μA DC beam;
sub-ns pulsing;
mono-energetic pulsed neutrons via 7Li(p,n);
fast-neutron beam line
ion microprobe;
general purpose scattering chamber

5.5 MV CN single ended Van de Graaff
C\textsuperscript{7}LYC efficiency measurements at UML

- Directly measure C\textsuperscript{7}LYC efficiency at accelerator
- Mono-energetic neutrons via \textsuperscript{7}Li(p,n)\textsuperscript{7}Be
- Neutron production rate via \textsuperscript{7}Be assay (52-day half-life)
- One \textsuperscript{7}Be per neutron, 10\% $\beta$-decay branch, 479-keV $\gamma$-ray

In-situ lithium target evaporator

2018

2019

LiF on W backing 132 $\mu$g/cm\textsuperscript{2}

quartz viewer
diagnostic cross

Learning with Purpose

Chowdhury  NNSA-SSAP Symposium  Albuquerque  Feb 20, 2019
C$^7$LYC tests (2018)

Neutron spectrum from $^7\text{Li}(p, n)^7\text{Be}$

$^7\text{Li}(p, n)^7\text{Be}$ (g.s)

3” x 3”

429 keV

$^7\text{Li}(p, n)^7\text{Be}^*$

Neutron energy (keV)

Stay tuned for 2019 results
β-delayed neutrons at CARIBU: $^{94}\text{Rb} \rightarrow ^{94}\text{Sr}$

Test experiment unsuccessful, to be repeated in new low-background CARIBU hall.
going more neutron-rich at NSCL
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**Table Values:***

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**Notes:**

- Z represents the atomic number.
- Si represents the element symbol.
- % values indicate the percentage of a particular isotope.
- MS values indicate the mean life span in seconds.

**Chowdhury**

**NNSA-SSAP Symposium**

**Albuquerque**

**Feb 20, 2019**
test experiment with $\text{LaBr}_3$ array & SEGA

Rate estimates (current technology)

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80 pnA $^{48}$Ca LISE++

4\(\pi\) shell of 3”x3” $C^7$LYC

Collaborators: B. Crider, S. Liddick et al.
fission neutron spectroscopy with C$^7$LYC

12 $\mu$Ci $^{252}$Cf source

C$^7$LYC+CHICO+GRETINA

$\Delta t$-C$^7$LYC-CHICO

Collaborator: S. Zhu

Chowdhury

NNSA-SSAP Symposium

Albuquerque

Feb 20, 2019
Summary & Outlook

- LANL (n,n’) proof-of-principle experiment a success
- Machine learning algorithms capable of n-γ discrimination
- Actinide contaminants need tolerance specifications

- $^{35}$Cl(n,p) cross-sections under analysis at LANL (necessary for simulations)
- Efficiency measurements ongoing at UML Van de Graaff
- Beta-delayed neutron measurements awaited at new CARIBU hall
- New fission neutron data with GRETINA and CHICO2
- Beta-delayed neutron tests at NSCL to be analyzed
- C$^7$LYC: auxiliary detector candidate for FRIB decay station?

Thank you for your attention!