LBNL/UC Report

12 November 2021

Lee A. Bernstein

Department of Nuclear Engineering
University of California – Berkeley

Nuclear Science Division
Lawrence Berkeley National Laboratory

http://nucleardata.berkeley.edu

BLUF: A short talk about lots of stuff

- Our group works collaboratively with numerous sponsors/partners on nuclear data related projects.
  - DOE/NNSA-NA22, DOE-NE, DOE-IP, Google, UC
  - 19 peer-reviewed papers + 6 dissertations in FY21

There's no way that I can cover all of this in 20 min.

- There's been a good deal of outreach work done to NASA, DTRA and MDA that I won't be able to report on, but I'm happy to discuss with anyone in the community offline
- The best way to learn about our work is to check our website – https://nucleardata.berkeley.edu

FY21 Personnel & FTE Breakdown

Name	Position	USNDP Activity	USNDP %	Other support
L.A. Bernstein	Joint Appt.	Coord, Measurements (n,n'γ)	50%	NA-22, UC, Isotopes
M.S. Basunia	Staff	ENSDF, XUNDL	90%	Isotopes
A.M. Hurst	Staff (UC)	(n,γ), (n,n'γ), website	10%	NA-22, DTRA
J.C. Batchelder	Staff (UC)	α/β-particle eval., ENSDF	75%	Isotope Program
B.L. Goldblum	Staff	AI/ML, Measurements	33%	NA-22, ARPA-E
A.S. Voyles	Staff (UC)	Reac. measure., website	25%	Isotope Program
J.A. Brown	Staff (UC)	^{238}U(n,n'γ), (n,f) yields	25%	DOE-NE, NA-22
J.T. Morrell*	GS→PD	(n,x) Isotope Production	0%	Isotope Program
C. Apgar*	GS	Sb(p,x) to 200 MeV	0%	Isotope Program
J. Matheny*	GS	Gamma-Xray Database	0%	DTRA
E.F. Matthews*	GS	Fission modeling	0%	NSSC Fellow
M. Fox*	GS	^{93}Nb,^{75}As(p,x) to 200 MeV	0%	Isotope Program
J.M. Gordon*	GS	^{56}Fe(n,n'γ)	0%	NE, LLNL
W. Younes	Consultant	ML, Fission Cov.	40%	N/A
P. Vincente-Valdez*	GS*	ML for reaction eval.	25%	UC
J. Tuli	Consultant	ENSDF	40%	n.a.
C. Romano	Consultant	Coordination (NDWG)	15%	n.a.

USNDP ≈30%

**GS limited to 50%*

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FY21 Graduates

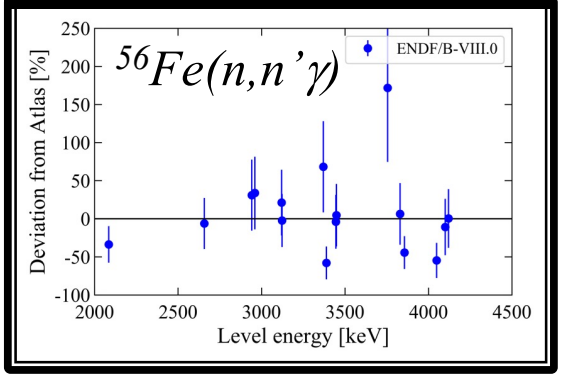
Mass chain/nuclide Evaluation (Shamsu)

- **Publications**
  - A=23 - NDS 171, 1 (2021) – M.S. Basunia, A. Chakraborty
  - A=233 – NDS 170, 499 (2020) – B. Singh, J. Tuli, E. Browne
- **Submitted: 24.5 nuclides**
  - A=24 (8 nuclides) – M.S. Basunia, A. Chakraborty
  - A=213 (12 nuclides) – M.S. Basunia
  - A=231 (9 nuclides) – B. Singh (4.5), J. Tuli (4.5)
- **Addressed reviewer's comments (resubmitted):**
  - A=186 J.C. Batchelder, A.M. Hurst, M.S. Basunia
- **Reviewed 2 mass chains**
  - M.S. Basunia (1), J.C. Batchelder (1)
- **In progress**
  - A=191 – M.S. Basunia

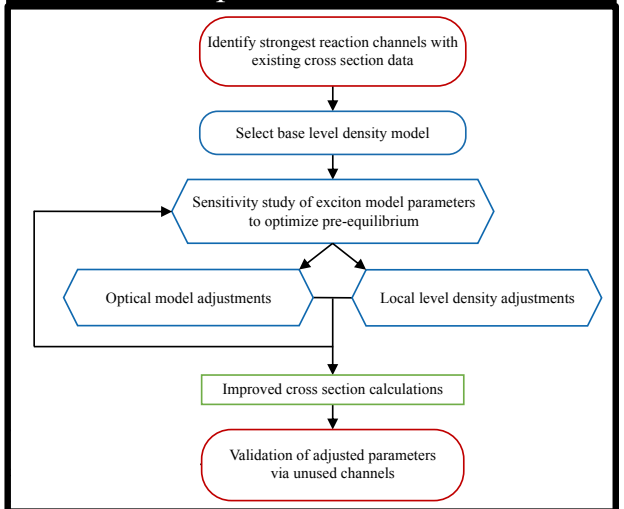
Berkeley works to address identified evaluation, validation and experimental nuclear data needs that support *and complement* the "Flagship" nuclear databases

The first (n_{fast},n'γ) benchmark database

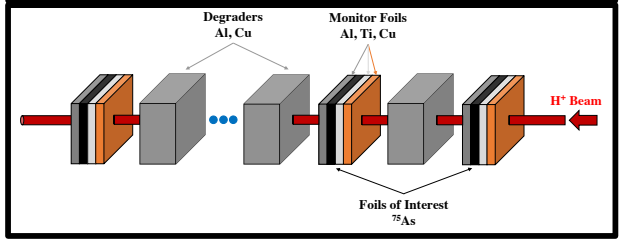
ENDF Validation



Evaluation of (p,x) data for $E_p \geq 100$ MeV

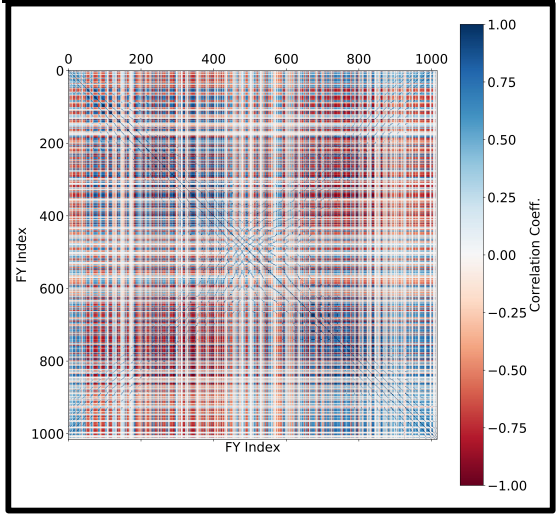


TREND (BNL & LANL)



New FPY & (n,n'γ) data

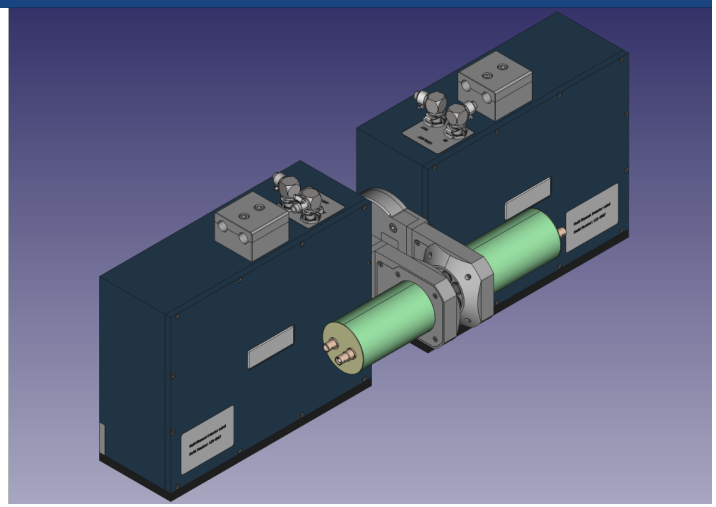
FPY covariance database

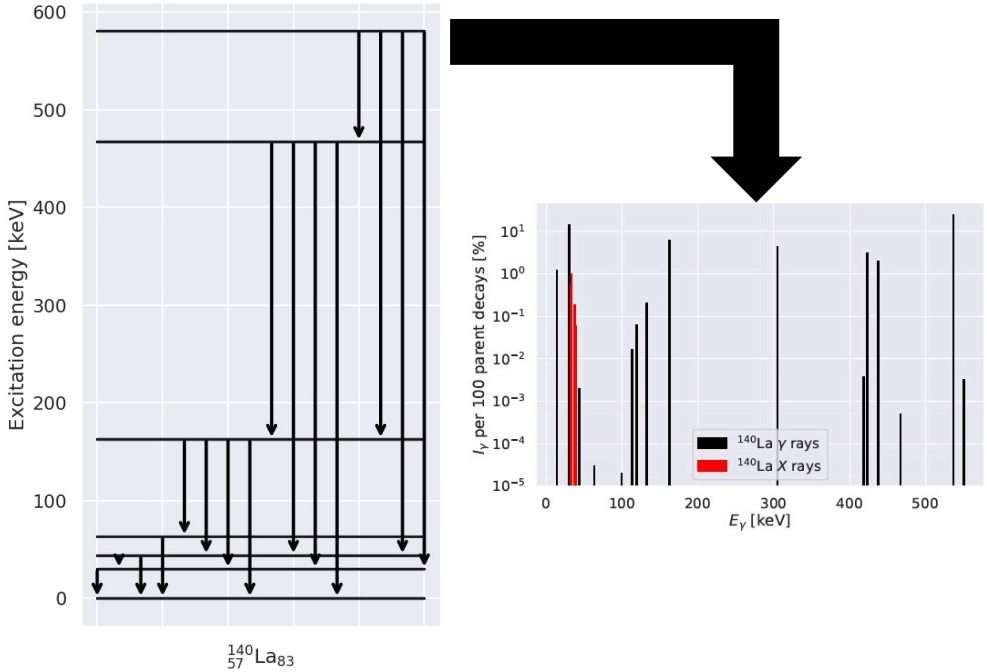


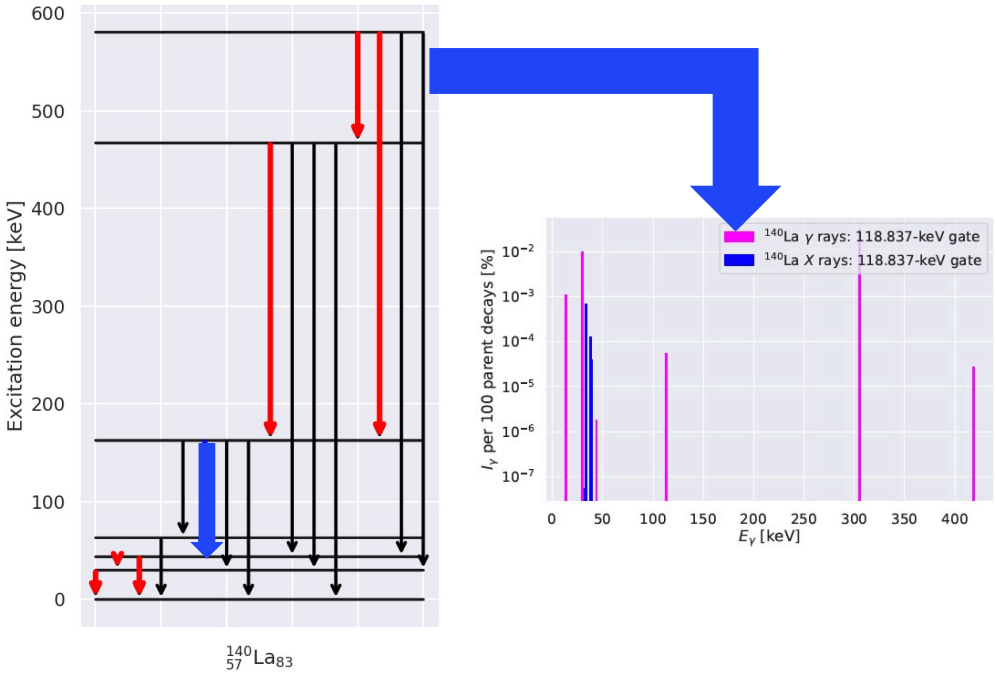
https://nucleardata.berkeley.edu/#research

Aaron is developing a new coincident decay database in collaboration with Bruce Pierson (PNNL)

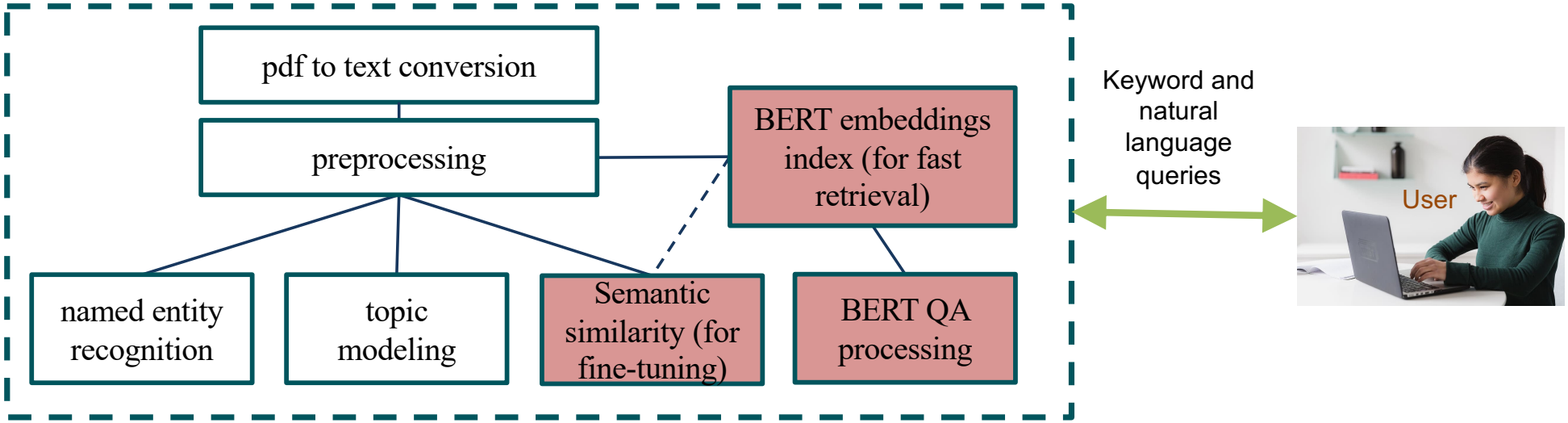
- DTRA has funded the production of a robust portable γ/X-ray coincidence detector system being developed at PNNL.
- Aaron has developed an ENSDF-sourced database that provides *correct coincident intensities* of γ-rays/X-rays emitted via α-, β-, γ- or EC-decay to a specific final level for use with this detector.





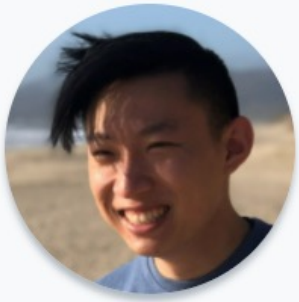


Bethany is developing NucScholar - A Natural Language Processing for Nuclear Science References



The NucScholar Team

Char Juin Chin
Undergraduate Student



Jonathan Li
Undergraduate Student

Bethany Goldblum
Research Scientist

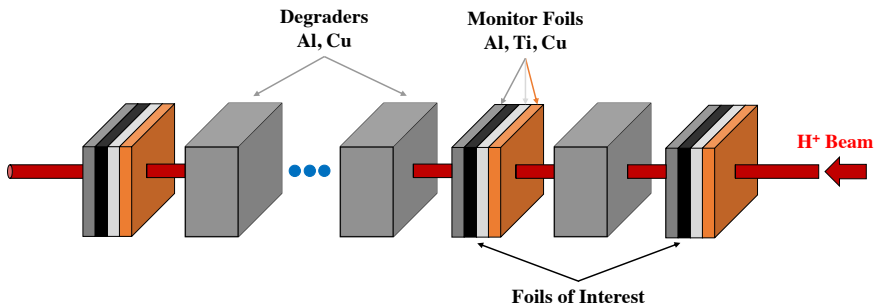
Laura Shi
Undergraduate Student

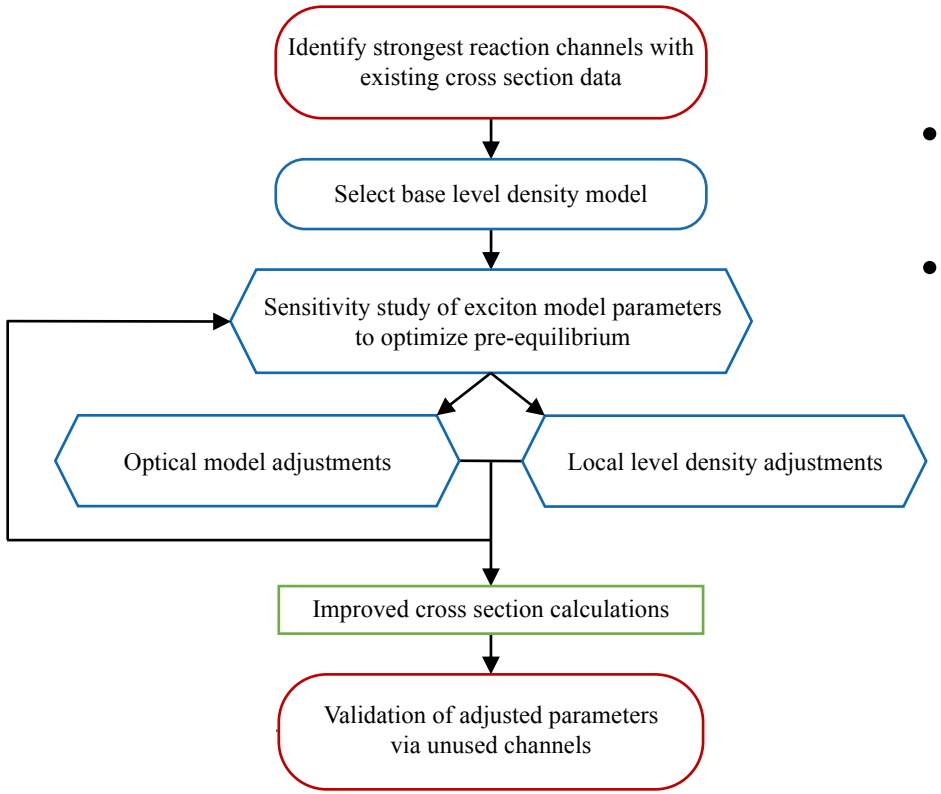
Walid Younes
Consultant

FY21 Publications – Evaluation (5)

1. ***P. Vicente-Valdez***, ***L.A. Bernstein***, and M. Fratoni., "Nuclear data evaluation augmented by machine learning," Ann. Nucl. Energy, 163, 108596 (2021), https://doi.org/10.1016/j.anucene.2021.108596
2. ***E. F. Matthews***, ***L. A. Bernstein***, and ***W. Younes***, "Stochastically estimated covariance matrices for independent and cumulative fission yields in the ENDF/B-VIII.0 and JEFF-3.3 evaluations," At. Data Nucl. Data Tables, 101441, (2021), https://doi.org/10.1016/j.adt.2021.101441
3. ***A.M. Hurst***, ***L.A. Bernstein***, T. Kawano, ***A.M. Lewis***, and ***K. Song***, "The Baghdad Atlas: A relational database of inelastic neutron-scattering (n,n′γ) data," Nuc. Inst. Meth. A 995, 165095. (2021), https://doi.org/10.1016/j.nima.2021.165095
4. B. Singh, ***J.K. Tuli***, E. Browne. Nuclear Data Sheets for A=233. 170, 499 (2020). https://doi.org/10.1016/j.nds.2020.11.002
5. ***M.S. Basunia***, Anagha Chakraborty. Nuclear Data Sheets for A=23. Vol. 171, January 2021, Pages 1-252. https://doi.org/10.1016/j.nds.2020.12.001

We are developing a high-energy (p,x) modeling approach as part of a LANL-BNL-LBNL* collaboration (Morgan)





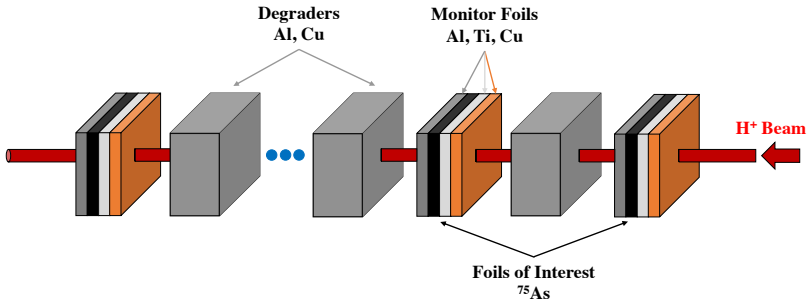
- We are using TALYS since it allows for the exploration of reaction model physics, is well-documented and is easy to use.
- Level density and exciton model parameters are adjusted to match the strongest independent channels
- The modeling is validated via comparison to cumulative channels.
- Publications:
  - M.B. Fox *et al.,* "Investigating high-energy proton-induced reactions on spherical nuclei: Implications for the preequilibrium exciton model" PRC 103, # 3, 034601, 3/21 https://doi.org/10.1103/PhysRevC.103.034601
  - M.B. Fox *et al.,* "Measurement and modeling of proton-induced reactions on arsenic from 35 to 200 MeV". Accepted for publication in PRC – 10/1/21

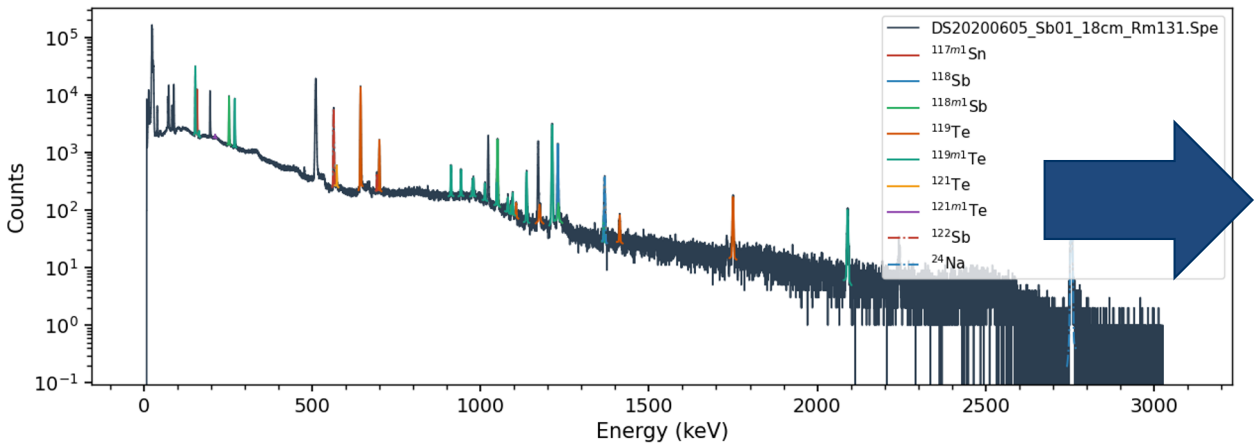
*Modeling collaborator: A. Koning

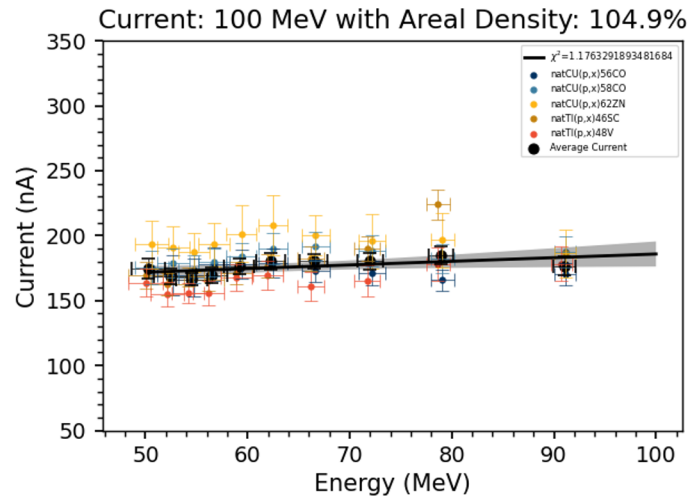
Curie* - A Python Toolkit for Activation Analysis

Curie is a Python API toolkit that provides :

- Peak fitting for HPGe/α-spec detector data
- HPGe energy & efficiency calibration
- Charged-particle energy loss characterization
- General-purpose Bateman equation solver
- Isotopic mass and decay data from ENSDF
- API to search and retrieve reaction data from multiple libraries







13,791 downloads since release, ≈7,500 in FY21

[* https://jtmorrell.github.io/curie/build/html/index.html](https://jtmorrell.github.io/curie/build/html/index.html)

Jon Morrell

2021 Publications Reaction Measurement/Modeling (4)

6. D. L. Bleuel, ***L. A. Bernstein***, R. A. Marsh, ***J. T. Morrell***, B. Rusnak, and ***A. S. Voyles***, "Precision measurement of relative γ-ray intensities from the decay of ^{61}Cu," Appl. Radiat. Isot., 170, 109625 (2021), https://doi.org/10.1016/j.apradiso.2021.109625

7. ***A.S. Voyles, A. M. Lewis, J. T. Morrell, M. S. Basunia, L. A. Bernstein***, J. W. Engle, S. A. Graves, and ***E. F. Matthews***, "Proton-induced reactions on Fe, Cu, and Ti from threshold to 55 MeV," Eur. Phys. J. A, 57 (3), (2021), https://doi.org/10.1140/epja/s10050-021-00401-2

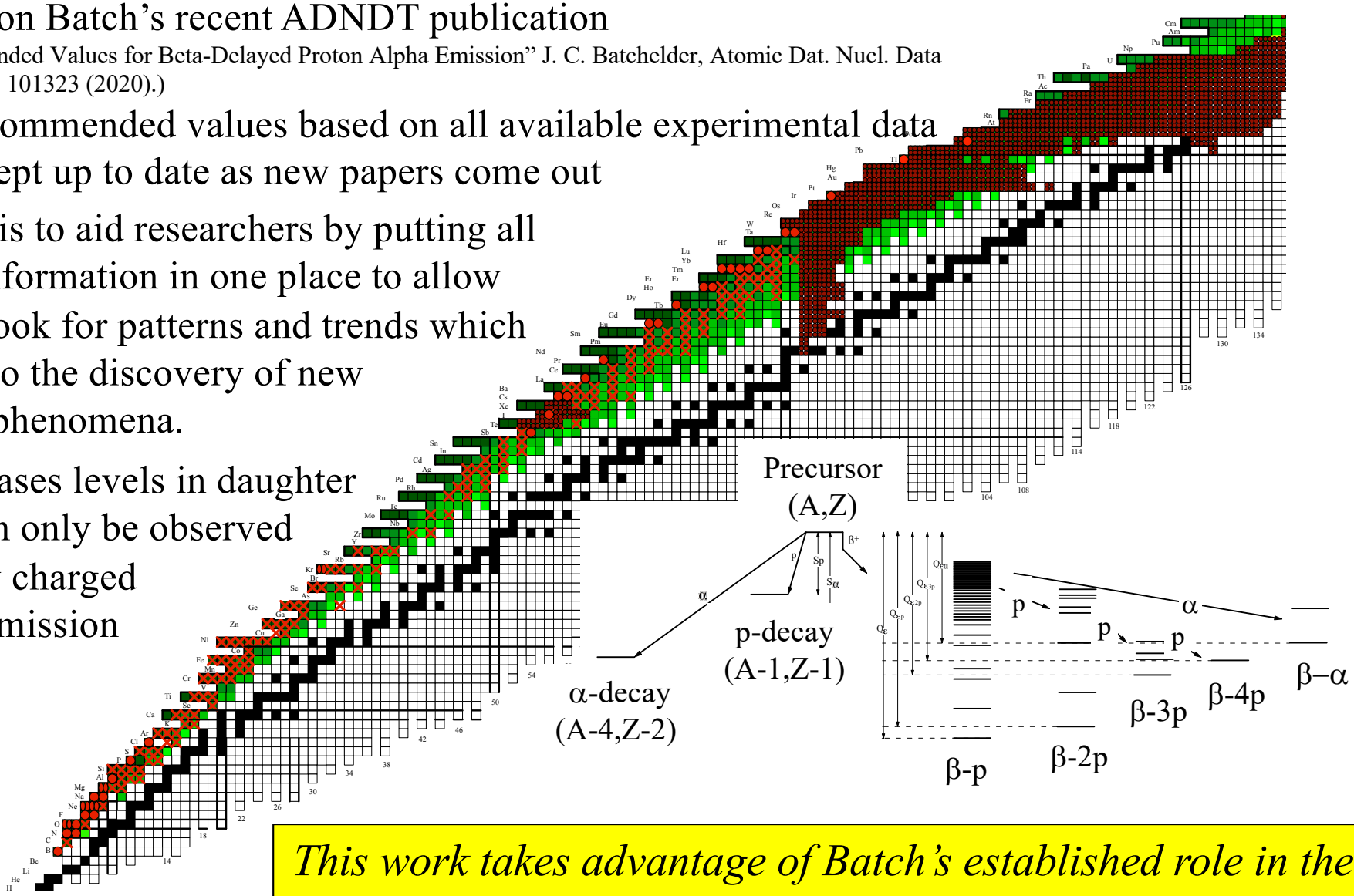
8. R. K. Chapman, ***A. S. Voyles***, N. Gharibyan, ***L. A. Bernstein***, and J. E. Bevins, "Measurement of the 160Gd(p,n)160Tb excitation function from 4–18 MeV using stacked-target activation," Appl. Radiat. Isot., 171, 109647 (2021), https://doi.org/10.1016/j.apradiso.2021.109647

9. ***M. B. Fox***, ***A. S. Voyles, J. T. Morrell, L. A. Bernstein, A. M. Lewis***, A. J. Koning, ***J. C. Batchelder***, E. R. Birnbaum, C. S. Cutler, D. G. Medvedev, F. M. Nortier, E. M. O'Brien, and C. Vermeulen, "Investigating high-energy proton-induced reactions on spherical nuclei: Implications for the preequilibrium exciton model," Phys. Rev. C, 103 (3), 034601 (2021), https://doi.org/10.1103/PhysRevC.103.034601

This research is supported in part by the U.S. Department of Energy Isotope Program, managed by the Office of Science for Isotope R&D and Production

We are developing an online* compilation and evaluation of heavy charged particle emitting (βxp, βα, xp, α) rare isotopes

- Expands on Batch's recent ADNDT publication
  - "Recommended Values for Beta-Delayed Proton Alpha Emission" J. C. Batchelder, Atomic Dat. Nucl. Data Tables **132**, 101323 (2020).)
- Gives recommended values based on all available experimental data
- Will be kept up to date as new papers come out
- The goal is to aid researchers by putting all current information in one place to allow users to look for patterns and trends which can lead to the discovery of new physical phenomena.
- In most cases levels in daughter nuclei can only be observed via heavy charged particle emission

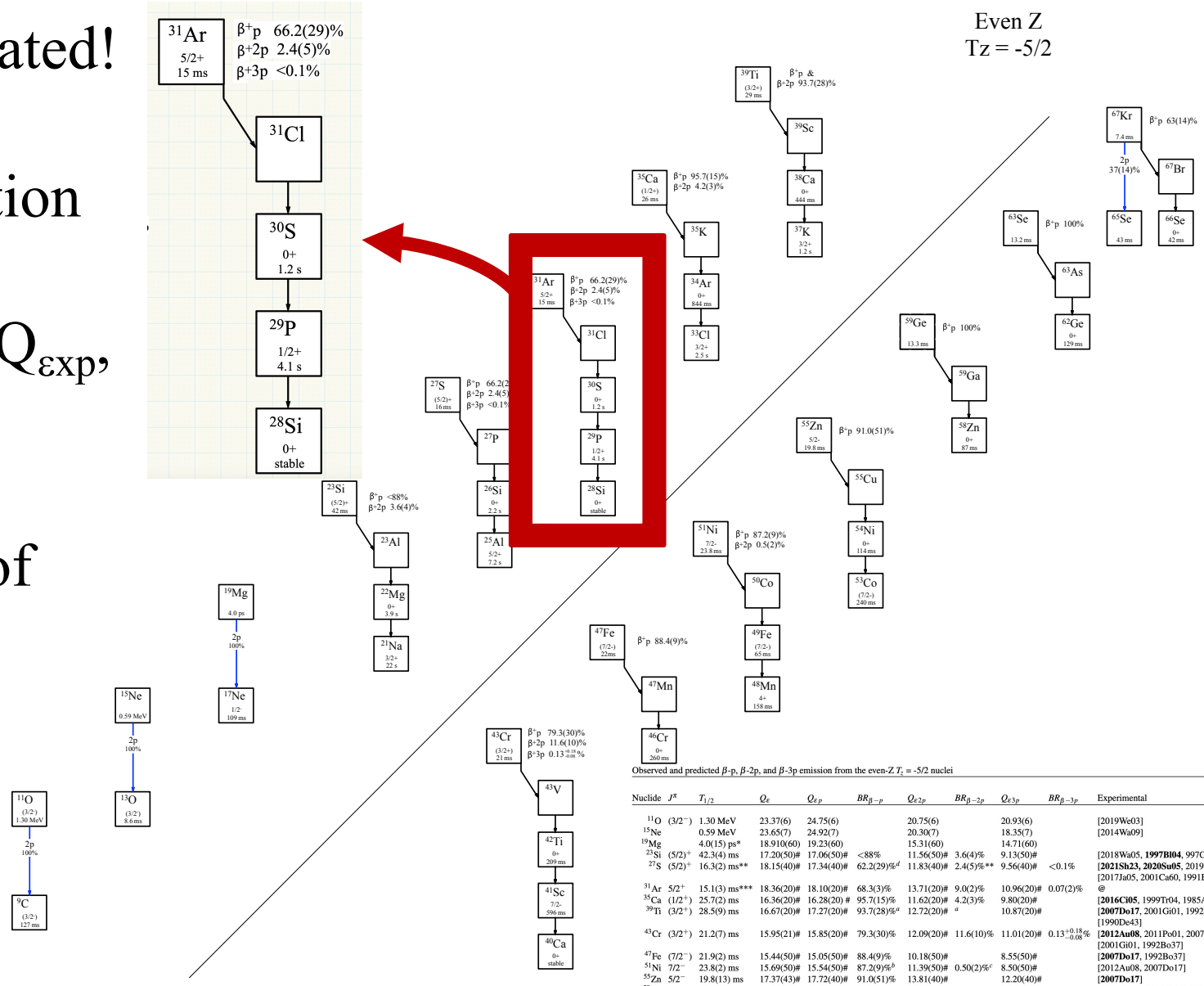


This work takes advantage of Batch's established role in the field to enable cutting edge research in the FRIB era.

*Web interface courtesy of A.M. Hurst

We are developing an online* compilation and evaluation of heavy charged particle emitting (βxp, βα, xp, α) rare isotopes

- Physics Motivated!
- Organized by isospin projection (T_z)
- Measured Q_ε, $Q_{\varepsilon xp}$, S_p, S_α, $Q_{\varepsilon\alpha}$ branchings
- Complete set of up-to-date references
- Downloadable pdf, CSV and JSON files



Observed and predicted β-p, β-2p, and β-3p emission from the even-Z T_z = -5/2 nuclei

Nuclide	J^π	$T_{1/2}$	Q_ε	$Q_{\varepsilon p}$	$BR_{\beta-p}$	$Q_{\varepsilon 2p}$	$BR_{\beta-2p}$	$Q_{\varepsilon 3p}$	$BR_{\beta-3p}$	Experimental
^{11}O	(3/2$^-$)	1.30 MeV	23.37(6)	24.75(6)		20.75(6)		20.93(6)		[2019We03]
^{15}Ne		0.59 MeV	23.65(7)	24.92(7)		20.30(7)		18.35(7)		[2014Wa09]
^{19}Mg		4.0(15) ps*	18.910(60)	19.23(60)		15.31(60)		14.71(60)		
^{23}Si	(5/2)$^+$	42.3(4) ms	17.20(50)#	17.06(50)#	<88%	11.56(50)#	3.6(4)%	9.13(50)#		[2018Wa05, **1997Bl04**, 997Cz02]
^{27}S	(5/2)$^+$	16.3(2) ms**	18.15(40)#	17.34(40)#	62.2(29)%[d]	11.83(40)#	2.4(5)%**	9.56(40)#	<0.1%	[**2021Sh23, 2020Su05**, 2019Su14] [2017Ja05, 2001Ca60, 1991Bo32]
^{31}Ar	5/2$^+$	15.1(3) ms***	18.36(20)#	18.10(20)#	68.3(3)%	13.71(20)#	9.0(2)%	10.96(20)#	0.07(2)%	@
^{35}Ca	(1/2$^+$)	25.7(2) ms	16.36(20)#	16.28(20) #	95.7(15)%	11.62(20)#	4.2(3)%	9.80(20)#		[**2016Ci05**, 1999Tr04, 1985Ay01]
^{39}Ti	(3/2$^+$)	28.5(9) ms	16.67(20)#	17.27(20)#	93.7(28)%[a]	12.72(20)#	[a]	10.87(20)#		[**2007Do17**, 2001Gi01, 1992Mo15] [1990De43]
^{43}Cr	(3/2$^+$)	21.2(7) ms	15.95(21)#	15.85(20)#	79.3(30)%	12.09(20)#	11.6(10)%	11.01(20)#	$0.13^{+0.18}_{-0.08}$%	[**2012Au08**, 2011Po01, 2007Do17] [2001Gi01, 1992Bo37]
^{47}Fe	(7/2$^-$)	21.9(2) ms	15.44(50)#	15.05(50)#	88.4(9)%	10.18(50)#		8.55(50)#		[**2007Do17**, 1992Bo37]
^{51}Ni	7/2$^-$	23.8(2) ms	15.69(50)#	15.54(50)#	87.2(9)%[b]	11.39(50)#	0.50(2)%[c]	8.50(50)#		[2012Au08, 2007Do17]
^{55}Zn	5/2$^-$	19.8(13) ms	17.37(43)#	17.72(40)#	91.0(51)%	13.81(40)#		12.20(40)#		[**2007Do17**]
^{59}Ge		13.3(17) ms	17.39(43)#	18.64(40)#	100%	16.36(40)#		15.67(40)#		[2017GoZT, 2016Go26, 2015Ci06]
^{63}Se		13.2(39) ms	16.65(54)#	18.00(52)#	100%	15.70(50)#		15.46(50)#		[2017GoZT, 2016Go26]
^{67}Kr		7.4(30) ms	16.98(52)#	18.82(47)#	63(14)%[e]	16.81(43)#		16.90(42)#		[2017GoZT, 2016Go26]

2021 Publications - Rare Isotope Decay Data (4)

10. E. H. Wang, J. M. Eldridge, N. T. Brewer, J. H. Hamilton, ***J. C. Batchelder***, Y. X. Liu, Y. Sun, C. Brown, C. J. Zachary, B. M. Musangu, A. V. Ramayya, K. P. Rykaczewski, C. J. Gross, R. Grzywacz, M. Madurga, D. Miller, D. W. Stracener, C. Jost, E. F. Zganjar, J. A. Winger, M. Karny, S. V. Paulauskas, S. H. Liu, M. Wolinska-Cichocka, S. W. Padgett, A. J. Mendez, K. Miernik, A. Fijalkowska, and S. V. Ilyushkin, "Long-lived isomeric states and quasiparticle band structures in neutron-rich ^{162,164}Gd nuclei from β decay," Phys.Rev. C 103 (1), 014317 (2021), https://doi.org/10.1103/PhysRevC.103.014317

11. S. Go, R. Grzywacz, C. Mazzocchi, S. N. Liddick, M. Alshudifat, ***J. C. Batchelder***, T. Baumann, A. A. Ciemny, T. N. Ginter, K. Kolos, A. Korgul, S. V. Paulauskas, C. J. Prokop, M. M. Rajabali, K. P. Rykaczewski, S. Taylor, and Y. Xiao, "Mapping of the fragmentation of the νf5/2→πf7/2 transition in decay of ^{73}Co→^{73}Ni," Phys. Rev. C. 102 (4), 044331 (2020), https://doi.org/10.1103/PhysRevC.102.044331

12. C. J. Zachary, N. T. Brewer, ***J. C. Batchelder***, E. Wang, J. H. Hamilton, J. M. Eldridge, B. M. Musangu, A. V. Ramayya, C. J. Gross, K. P. Rykaczewski, R. Grzywacz, M. Madurga, D. Miller, D. W. Stracener, C. Jost, E. F. Zganjar, J. A. Winger, M. Karny, S. V. Paulauskas, S. H. Liu, M. Wolinska-Cichocka, S. W. Padgett, A. J. Mendez, K. Miernik, A. Fijalkowska, S. V. Ilyushkin, A. C. Dai, and F. R. Xu, "New transitions and levels in ^{163}Tb obtained from β decay studies," Phys Rev. C 102 (4), 044302 (2020), https://doi.org/10.1103/PhysRevC.102.044302

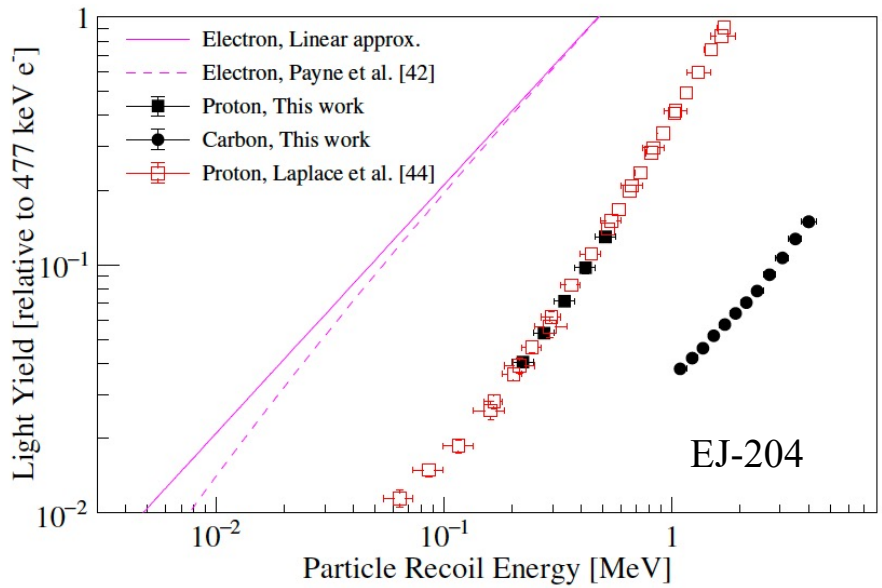
13. ***J. C. Batchelder, C. Apgar***, N. T. Brewer, C. J. Gross, R. Grzywacz, S. Ilyushkin, M. Madurga, K. Miernik, S. W. Padgett, S. V. Paulauskas, W. Peters, C. Rasco, K. P. Rykaczewski, D. Stracener, J. A. Winger, M. Wolin´ska-Cichocka, E. F. Zganjar, D. Bardayan, M. E. Howard, B. Manning, M. Matos, A. Mendez, D. Miller, A. Ratkiewski, and E. H. Wang, Levels in ^{125}Cd populated by the β-decay of ^{125m}Ag and ^{125}Ag. Phys. Rev. C. 104, 024308 (2021). https://doi.org/10.1103/PhysRevC.104.024308

10 papers submitted and published in the last 4 years

WANDA 2020 and WoNDRAM 2021 Roadmaps call for scintillator quenching data

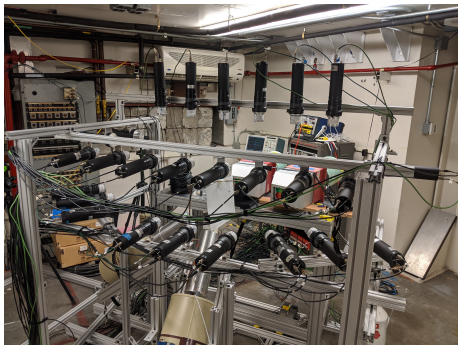
"An understanding of quenching phenomena in organic scintillators is a crosscutting need."
–WANDA 2020 Roadmap

"It is recommended that funding agencies prioritize experimental studies of scintillator response—including light yield, electron light nonproportionality, and quenching factors for heavy nuclei—as a key component of the science."
–WoNDRAM 2021 Roadmap

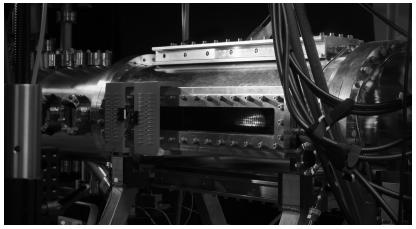


T.A. Laplace, B.L. Goldblum, et al. Phys. Rev. C (2021).

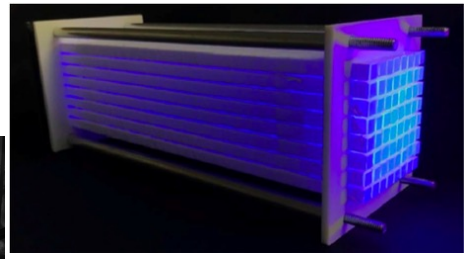
Wide range of applications:



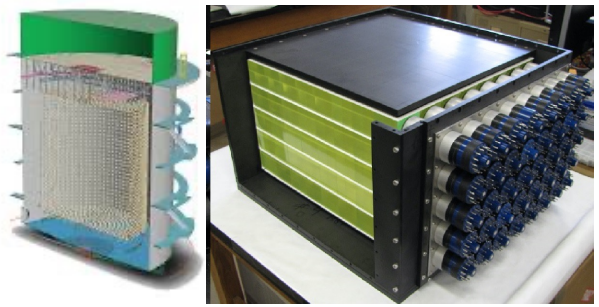
Nuclear physics (threshold estimation & forward modeling)



Fusion energy
(plasma diagnostics)



Nuclear security
(kinematic reconstruction for imaging)



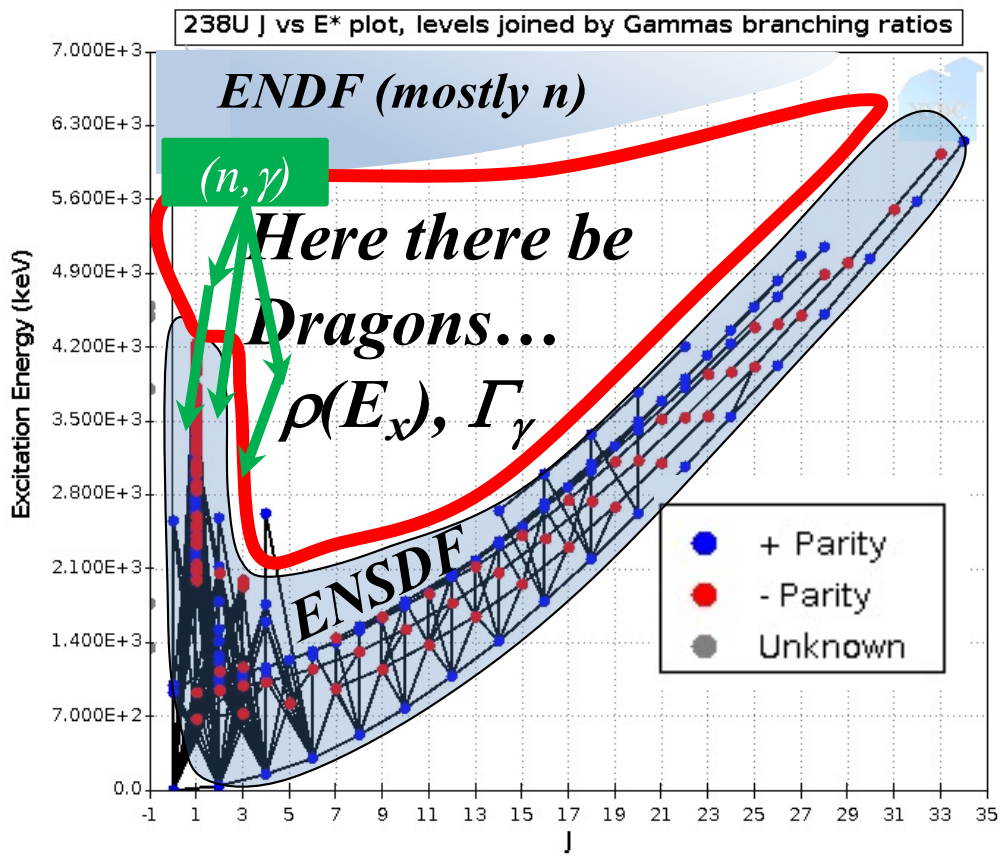
Neutrino detection
(background in IBD detectors)

2021 Publications Scintillator Characterization (4)

14. Lucas Q Nguyen, Gino Gabella, ***Bethany L Goldblum, Thibault A Laplace***, Joseph S Carlson, Erik Brubaker, and Patrick L Feng, "Boron-loaded organic glass scintillators," Nucl. Instrum. Meth. A 988, 164898 (2021), https://doi.org/10.1016/j.nima.2020.164898
15. ***T.A. Laplace, B.L. Goldblum***, J.E. Bevins, D.L. Bleuel, E. Bourret, ***J.A. Brown***, E.J. Callaghan, J.S. Carlson, P.L. Feng, and G. Gabella, "Comparative scintillation performance of EJ-309, EJ-276, and a novel organic glass," J. Instrum. 15 (11), P11020 (2020), https://doi.org/10.1088/1748-0221/15/11/P11020
16. ***T.A. Laplace, B.L. Goldblum***, J.J. Manfredi, ***J.A. Brown***, D.L. Bleuel, C.A. Brand, G. Gabella, ***J. Gordon***, and E. Brubaker. "Simultaneous measurement of organic scintillator response to carbon and proton recoils", Phys. Rev. C 104, 014609 – Published 9 July 2021 https://doi.org/10.1103/PhysRevC.104.014609
17. G. Gabella, ***B.L. Goldblum, T.A. Laplace***, J.J. Manfredi, ***J. Gordon***, Z.W. Sweger, E. Bourret, "Neutron Response of the EJ-254 Boron-Loaded Plastic Scintillator," IEEE Trans. Nucl. Sci. 68, 46 (2021). https://doi.org/10.1109/TNS.2020.3041215

Future directions: Structure beyond ENSDF

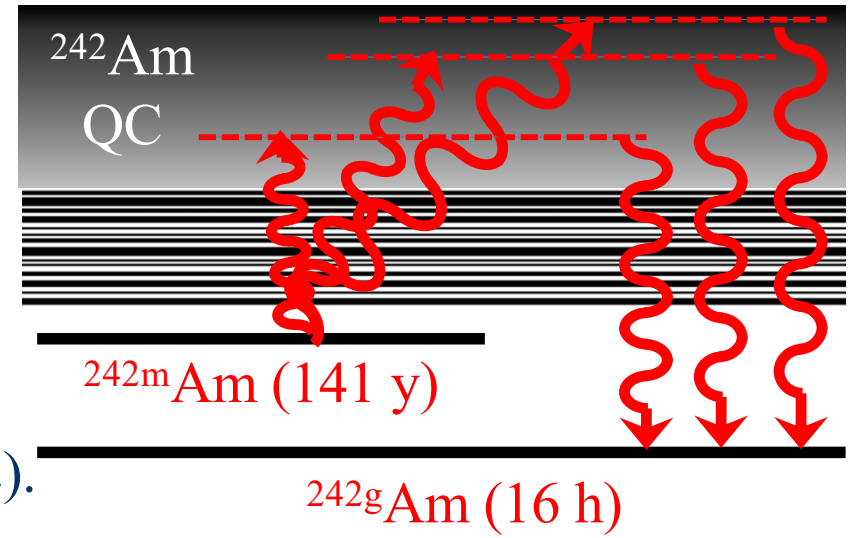
- There is a huge "evaluation gap" between ENSDF & ENDF – the Quasicontinuum (QC) region.
- The data in this region (level density and radiative strength) are key to modeling photonuclear and capture cross sections for:
  - Stellar nucleosynthesis;
  - Isotope Production;
  - Damage studies for nuclear energy and space exploration;
  - Active Interrogation for Nonproliferation
- FRIB will create a large body of this sort of data (β-Oslo method).
  - We are coupled to this community through the NSSC (Liddick) and our long-standing collaboration with the University of Oslo.

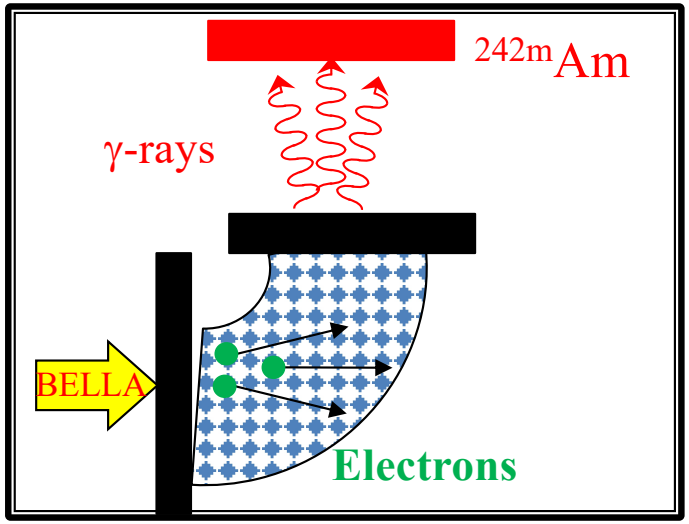


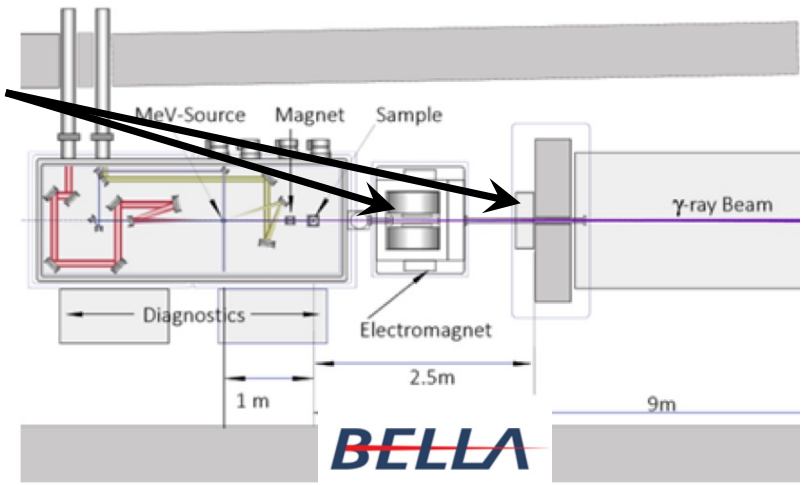
We are starting a search for a researchers who can work with the community to address this crosscutting nuclear data need

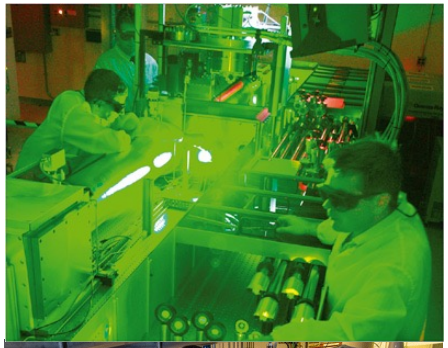
Google Project X is supporting us to explore the use of electrons and γ-rays from the BELLA laser to speed up the decay of nuclear isomers

1. The 141 year ^{242m}Am isomer is a problematic constituent of nuclear waster.
2. A UCB/LBNL team led by Lee Bernstein high energy photon beam from the BELLA laser will be used to populate QC states above the ^{242m}Am isomer (Step #1).
3. These states will feed the 16 hour ground state and its decay observed off-line. (Step #2).









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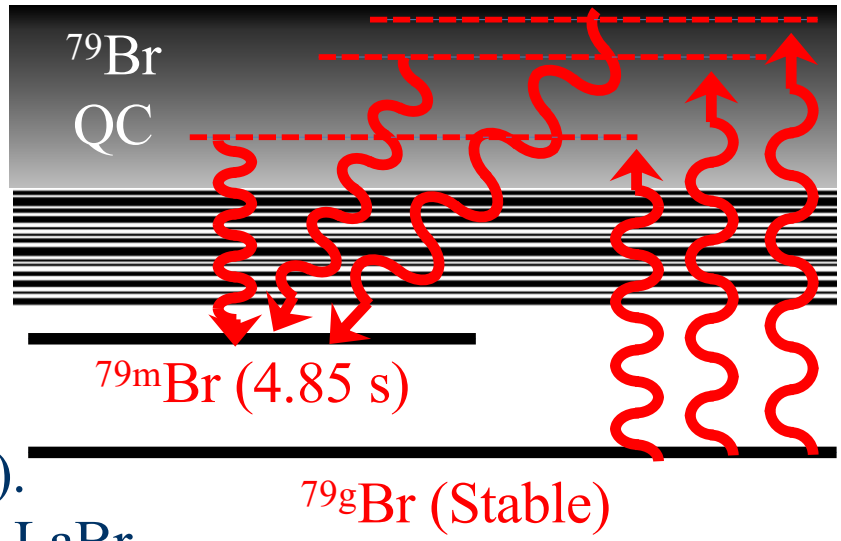
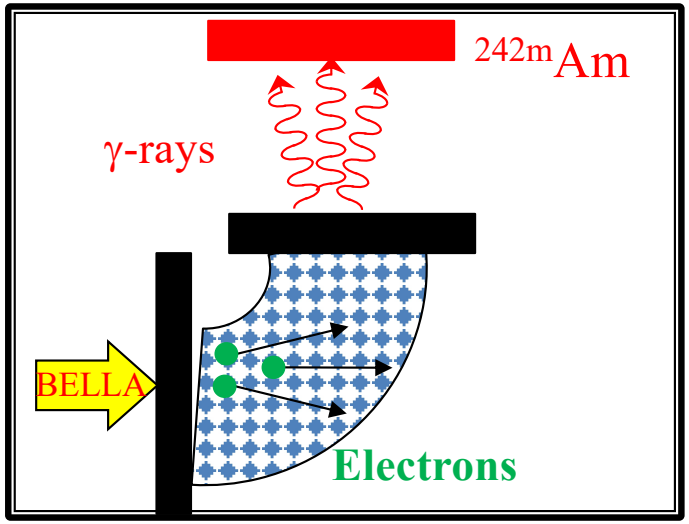
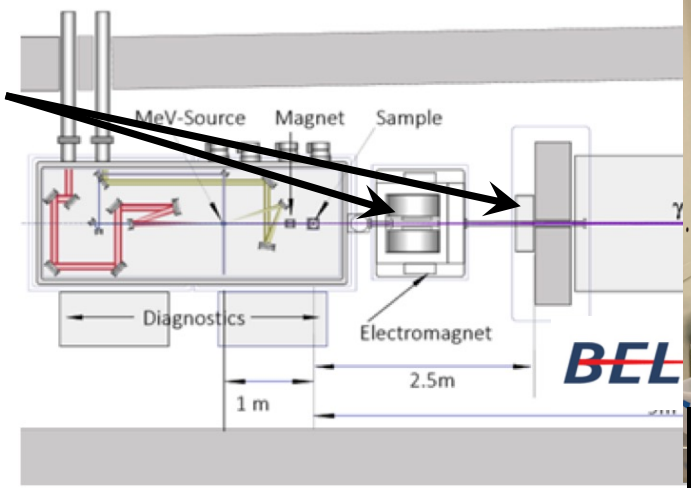
4. First proof-of-principle measurements using a LaBr and CLYC surrogate are planned for late 2021.







2021 Publications Quasicontinuum Structure/Lasers (2)

18. D. Gjestvang, S. Siem, F. Zeiser, J. Randrup, R. Vogt, J. N. Wilson, F. Bello-Garrote, ***L. A. Bernstein***, D. L. Bleuel, M. Guttormsen, A. Görgen, A. C. Larsen, K. L. Malatji, ***E. F. Matthews***, A. Oberstedt, S. Oberstedt, T. Tornyi, G. M. Tveten, and ***A. S. Voyles***, "Excitation energy dependence of prompt fission γ-ray emission from Pu241* ," Phys. Rev. C, 103 (3), 034609 (2021), https://doi.org/10.1103/PhysRevC.103.034609

19. Pascal Boller, Alex Zylstra, Paul Neumayer, ***Lee Bernstein***, Christian Brabetz, John Despotopulos, Jan Glorius, Johannes Hellmund, Eugene A. Henry, Johannes Hornung, Justin Jeet, Jadambaa Khuyagbaatar, Lotte Lens, Simon Roeder, Thomas Stoehlker, Alexander Yakushev, Yuri A. Litvinov, Dawn Shaughnessy, Vincent Bagnoud, Thomas Kuehl & Dieter H. G. Schneider, "First on-line detection of radioactive fission isotopes produced by laser-accelerated protons", Scientific Reports 10, 17183 (2020). https://doi.org/10.1038/s41598-020-74045-5

CY2020-2021 BAND Ph.D. Dissertations

1. "Uncertainty Analysis Procedures for Neutron-Induced Cross Section Measurements and Evaluations"

   Amanda Marie Lewis – Spring 2020* *NNL Staff*

2. "Fission plasmas and their novel application to power producing nuclear reactors in space"

   Austin Troy Lo – Fall 2020 *ORNL Postdoc*

3. "Advancements in the Nuclear Data of Fission Yields"

   Eric Francis Matthews – Spring 2021 *UCB Researcher*

4. "Nuclear Data Evaluation of High-Energy Proton-Induced Reactions for Isotope Production"

   Morgan B. Fox – Spring 2021 – *Terrestrial Energy Staff*

5. "Next-Generation Isotope Production via Deuteron Breakup" -

   Jonathan T. Morrell – Spring 2021 – *LANL Postdoc*

6. "Machine Learning Augmented Nuclear Data Evaluations" -

   Pedro Vincente-Valdez – Spring 2021 – *Senior AI Software Engineer at Mythic*

Future Colleagues - Our most valuable product

On the topic of education, I have one request

NSSC Nuclear Data Summer School

https://nssc.berkeley.edu/

- To be held either 6/22 or 1/23
- Hybrid in-person/online program at either UCB or UTK
- For the online program, Zoom will be used to broadcast lectures and to take live questions from virtual participants.
- We also plan to record lectures and make them available online

If you'd like to volunteer to lecture, please let us know!