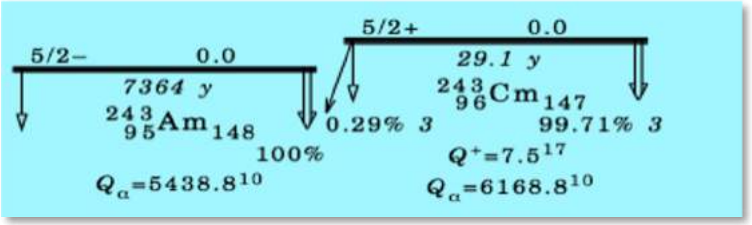
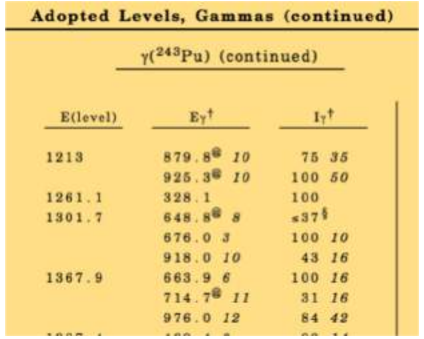
Status Report on Nuclear Data Activities at Oak Ridge National Laboratory

USNDP 2022

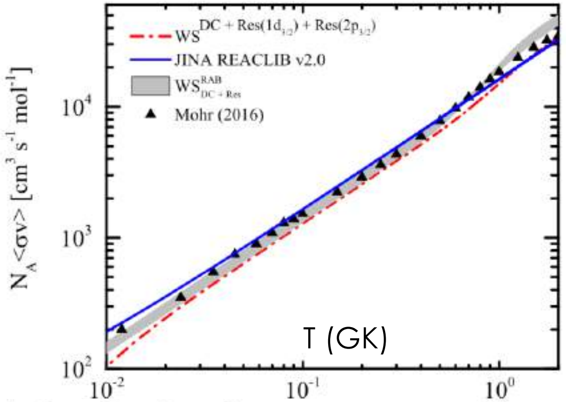
Michael Smith, Caroline Nesaraja, Larry Zhang

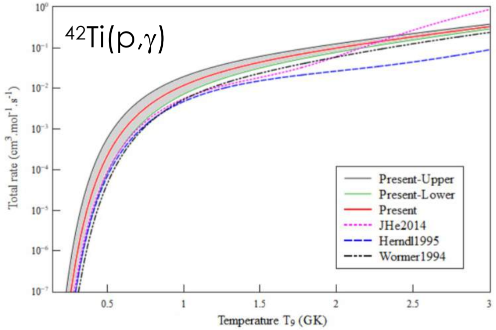
Members and Scope of Activities

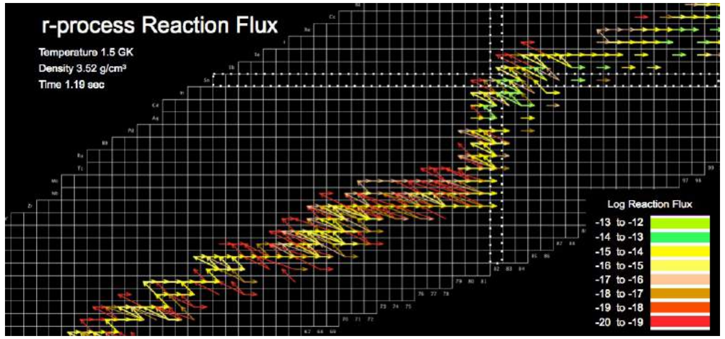


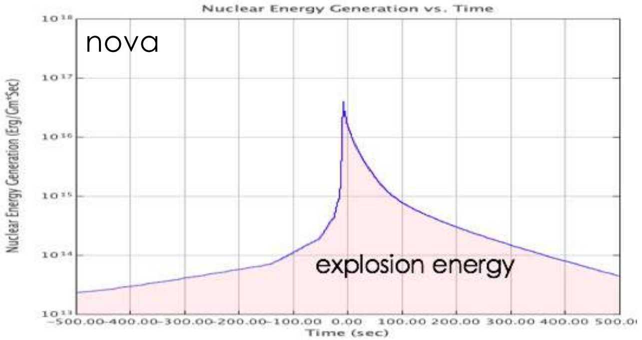


E(level)	Eγ†	Iγ†
1213	879.8@ 10	75 35
	925.3@ 10	100 50
1261.1	328.1	100
1301.7	648.8@ 8	≤37§
	676.0 3	100 10
	918.0 10	43 16
1367.9	663.9 6	100 16
	714.7@ 11	31 16
	976.0 12	84 42









- Members and Activities:
  - Caroline Nesaraja: Research Staff Member - ENSDF evaluator
  - Michael Smith: Research Staff Member - nuclear astro data, software systems
  - Larry Zhang : Student - nuclear astrophysics data

Murray Martin – Nuclear Data Pioneer

In Memoriam
Murray J. Martin, 1935-2022

Approved for public release. Distribution is unlimited

ORNL/TM-2022/1835

Guidelines for Nuclear Structure Evaluators

Murray J. Martin (ORNL/UTK)

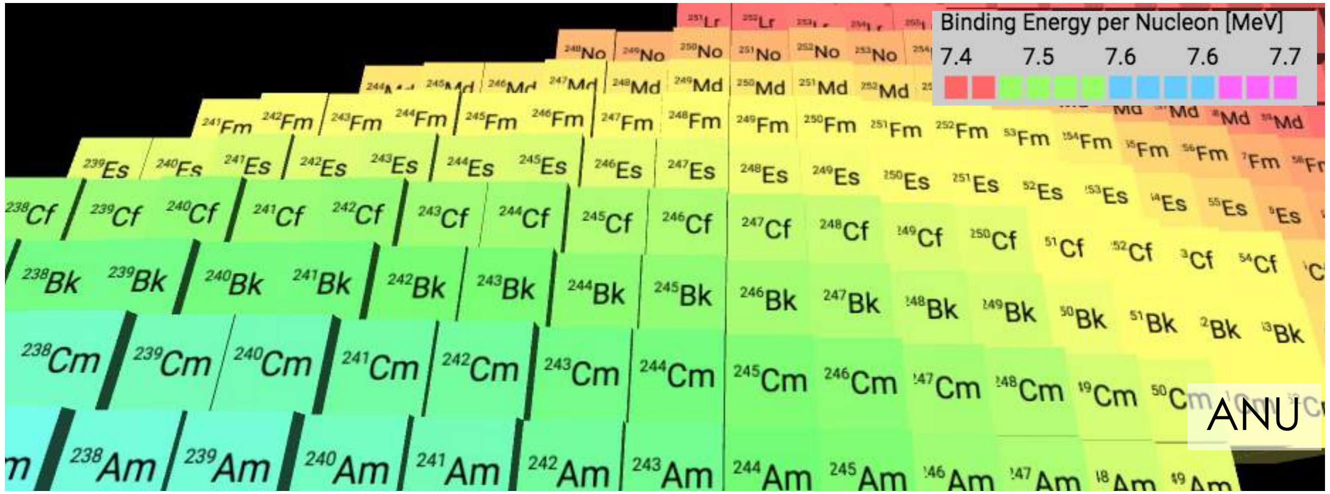
4/26/2021

The field of nuclear data lost a pioneer with the passing of Murray Martin on March 9, 2022.

Born in Regina, Canada in 1935, Murray Martin received his B.A. and M.A. in experimental physics from the University of Saskatchewan and his PhD in theoretical nuclear physics in 1962 from McMaster Univ. His thesis was entitled "A Study of the Low-Lying Excited Levels in the Even Lead Isotopes". He joined the NSF Data Project in 1962 in Washington, DC, and then followed that project as it moved to ORNL in 1964 as the Nuclear Data Project (NDP). Murray stayed with the NDP until his retirement in 1997 but resumed his work on a part-time basis in 2004 as a subcontractor to ORNL, which he continued until his last days.

Nuclear Structure Data
ENSDF Evaluations

Caroline Nesaraja



- **ORNL responsibility: A=241-249**
  A = 69

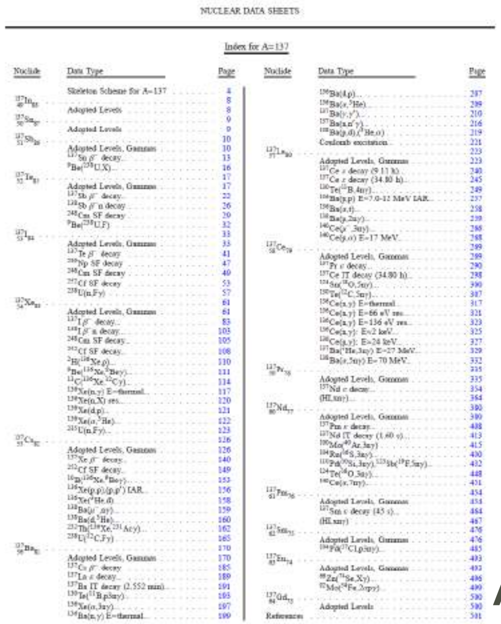
Mass Chain	Current ENSDF Database (from NNDC website)	
241	C.D. Nesaraja. NDS 130, 183 (2015)	(Lit cut-off Sept 2015)
242	Y. A. Akovali. NDS 96, 177 (2002)	(Lit cut-off Sept 2001)
243	C.D. Nesaraja & E.A. McCutchan. NDS 121, 695 (2014)	(Lit cut-off Sept 2013)
244	C.D. Nesaraja : NDS 146, 387 (2017)	(Lit cut-off Aug 2017)
245	E. Browne & J.K. Tuli. NDS 112, 447 (2011)	(Lit. cut-off June 2010)
246	E. Browne & J.K. Tuli. NDS 112, 1833 (2011)	(Lit. cut-off Jan 2011)
247	C. D. Nesaraja : NDS 125, 395 (2015)	(Lit. cut-off Mar 2014)
248	M.J. Martin :NDS 122, 377 (2014)	(Lit. cut-off Sept 2014)
249	K. Abusaleem: NDS 112, 2129 (2011)	(Lit. cut-off Dec 2010)
69	C.D. Nesaraja : NDS 115, 1 (2014)	(Lit. cut-off July 2013)

Nuclear Structure Data

ENSDF Evaluations

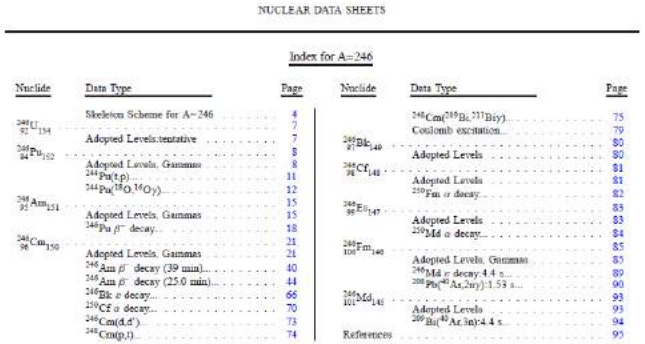
Caroline Nesaraja

Mass Chain	Evaluator	#Nuclides	Status
*137	Nesaraja	16	Editorial Review
246	Nesaraja	9	Submitted to NNDC
242	Martin/Nesaraja	9	Editorial Review


NUCLEAR DATA SHEETS

Index for A=137

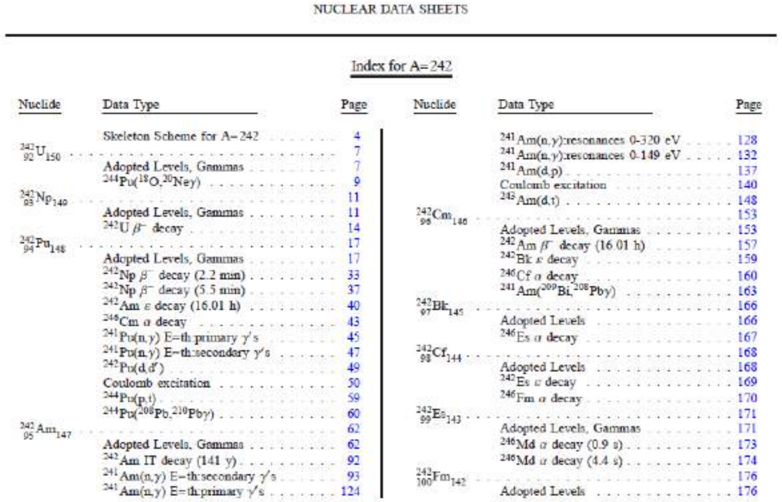
A=137


NUCLEAR DATA SHEETS

Index for A=246

Nuclide	Data Type	Page
	Skeleton Scheme for A=246	4
$^{246}_{92}$U$_{154}$		7
	Adopted Levels:tentative	7
$^{246}_{94}$Pu$_{152}$		8
	Adopted Levels, Gammas	8
	^{244}Pu(t,p)	11
	^{244}Pu(^{18}O,^{16}Oγ)	12
$^{246}_{95}$Am$_{151}$		15
	Adopted Levels, Gammas	15
	^{246}Pu β$^-$ decay	18
$^{246}_{96}$Cm$_{150}$		21
	Adopted Levels, Gammas	21
	^{246}Am β$^-$ decay (39 min)	40
	^{246}Am β$^-$ decay (25.0 min)	44
	^{246}Bk ε decay	66
	^{250}Cf α decay	70
	^{246}Cm(d,d')	73
	^{248}Cm(p,t)	74
	^{248}Cm(^{209}Bi,^{211}Biγ)	75
	Coulomb excitation	79
$^{246}_{97}$Bk$_{149}$		80
	Adopted Levels	80
$^{246}_{98}$Cf$_{148}$		81
	Adopted Levels	81
	^{250}Fm α decay	82
$^{246}_{99}$Es$_{147}$		83
	Adopted Levels	83
	^{250}Md α decay	84
$^{246}_{100}$Fm$_{146}$		85
	Adopted Levels, Gammas	85
	^{246}Md ε decay:4.4 s	89
	^{208}Pb(^{40}Ar,2nγ):1.53 s	90
$^{246}_{101}$Md$_{145}$		93
	Adopted Levels	93
	^{209}Bi(^{40}Ar,3n):4.4 s	94
References		95

A=246


NUCLEAR DATA SHEETS

Index for A=242

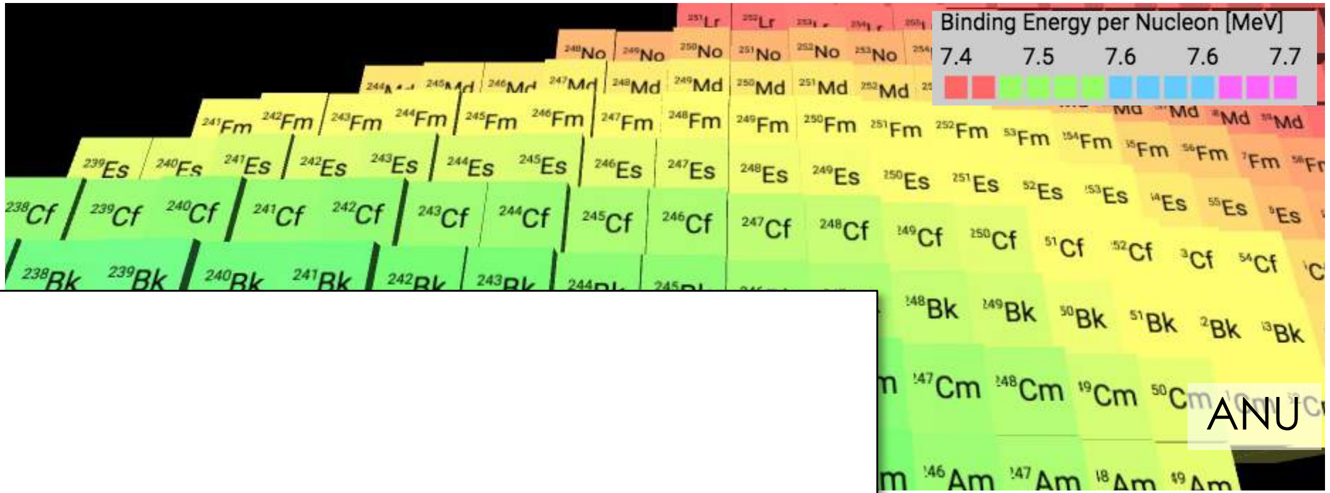
Nuclide	Data Type	Page
	Skeleton Scheme for A=242	4
$^{242}_{92}$U$_{150}$		7
	Adopted Levels, Gammas	7
	^{244}Pu(^{18}O,^{20}Neγ)	9
$^{242}_{93}$Np$_{149}$		11
	Adopted Levels, Gammas	11
	^{242}U β$^-$ decay	14
$^{242}_{94}$Pu$_{148}$		17
	Adopted Levels, Gammas	17
	^{242}Np β$^-$ decay (2.2 min)	33
	^{242}Np β$^-$ decay (5.5 min)	37
	^{242}Am ε decay (16.01 h)	40
	^{246}Cm α decay	43
	^{241}Pu(n,γ) E=th:primary γ's	45
	^{241}Pu(n,γ) E=th:secondary γ's	47
	^{242}Pu(d,d')	49
	Coulomb excitation	50
	^{244}Pu(p,t)	59
	^{244}Pu(^{208}Pb,^{210}Pbγ)	60
$^{242}_{95}$Am$_{147}$		62
	Adopted Levels, Gammas	62
	^{242}Am IT decay (141 y)	92
	^{241}Am(n,γ) E=th:secondary γ's	93
	^{241}Am(n,γ) E=th:primary γ's	124
	^{241}Am(n,γ):resonances 0-320 eV	128
	^{241}Am(n,γ):resonances 0-149 eV	132
	^{241}Am(d,p)	137
	Coulomb excitation	140
	^{243}Am(d,t)	148
$^{242}_{96}$Cm$_{146}$		153
	Adopted Levels, Gammas	153
	^{242}Am β$^-$ decay (16.01 h)	157
	^{242}Bk ε decay	159
	^{246}Cf α decay	160
	^{241}Am(^{209}Bi,^{208}Pbγ)	163
$^{242}_{97}$Bk$_{145}$		166
	Adopted Levels	166
	^{246}Es α decay	167
$^{242}_{98}$Cf$_{144}$		168
	Adopted Levels	168
	^{242}Es ε decay	169
	^{246}Fm α decay	170
$^{242}_{99}$Es$_{143}$		171
	Adopted Levels, Gammas	171
	^{246}Md α decay (0.9 s)	173
	^{246}Md α decay (4.4 s)	174
$^{242}_{100}$Fm$_{142}$		176
	Adopted Levels	176

A=242

Nuclear Structure Data

ENSDF Evaluations

Caroline Nesaraja



A=137

<u>September 2018</u>: Submitted A=137

December 2019: Reviewer's comments received for A=137

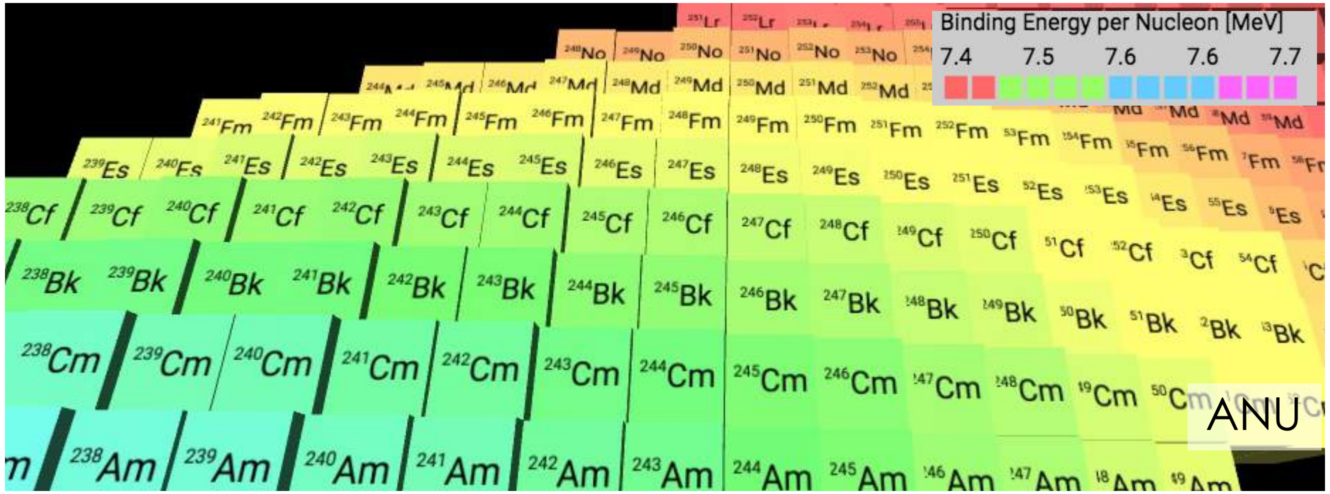
<u>August 2022</u>: Resubmitted A=137

Between September 2019- August 2022 (3 years lag time)

- 9400 changes since last version
- includes ^{137}Cs used for cancer treatment
- now includes numerical MTAS data not previously available
- also includes results from 24 new papers since 2018
- end result is a 514-page evaluation

Nuclear Structure Data Related Activities

Caroline Nesaraja



- Member – Int. Program Committee for ND2022 at LLNL (418 participants)

15th International Conference on Nuclear Data for Science and Technology (ND2022)

ND2022 is the latest in a series of conferences on nuclear data held every three years since 1978. This conference brings together international experts involved in generating and using nuclear data for a week of presentations and in-depth discussion.

ND2022 is being organized by LLNL and will be held July 24–29, 2022. The conference was originally scheduled to be held at the SAFE Credit Union Convention Center in Sacramento, California, but has been converted to a virtual event due to ongoing COVID-19 uncertainty.

More information about the conference is available at the ND2022 website.

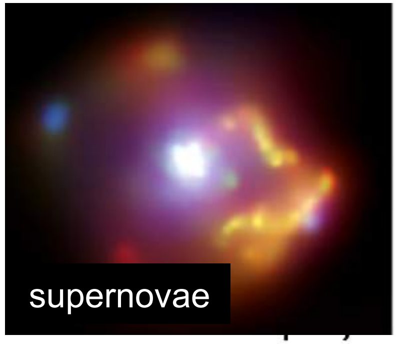
Research & Development Missions Resources Partnerships Careers News About

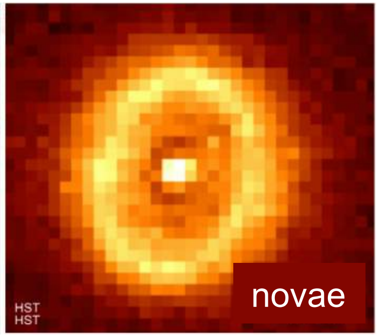
Lawrence Livermore National Laboratory

- Member – NSAC Nuclear Data Subcommittee

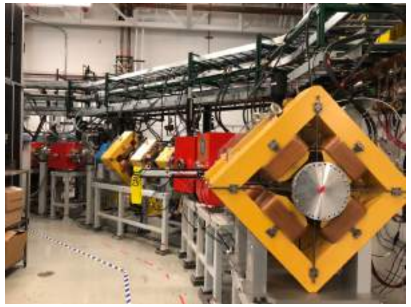
DOE/NSF Nuclear Science Advisory Committee

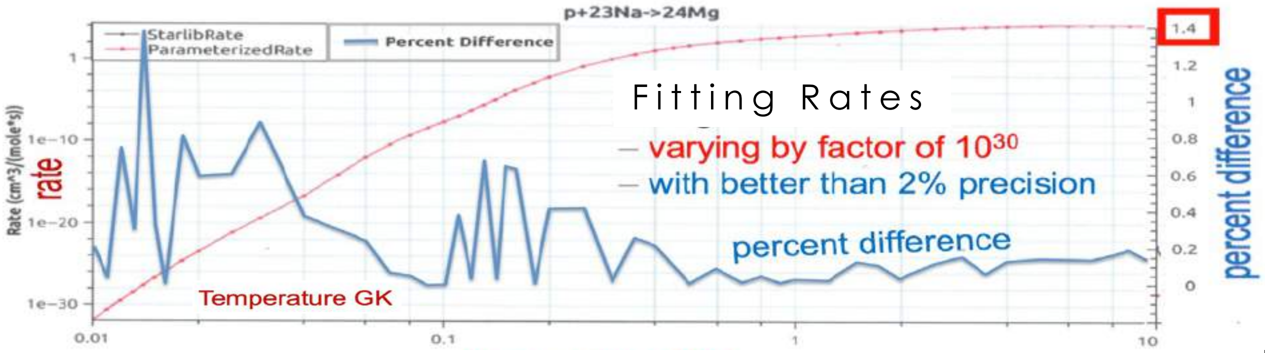
Nuclear Astrophysics Data

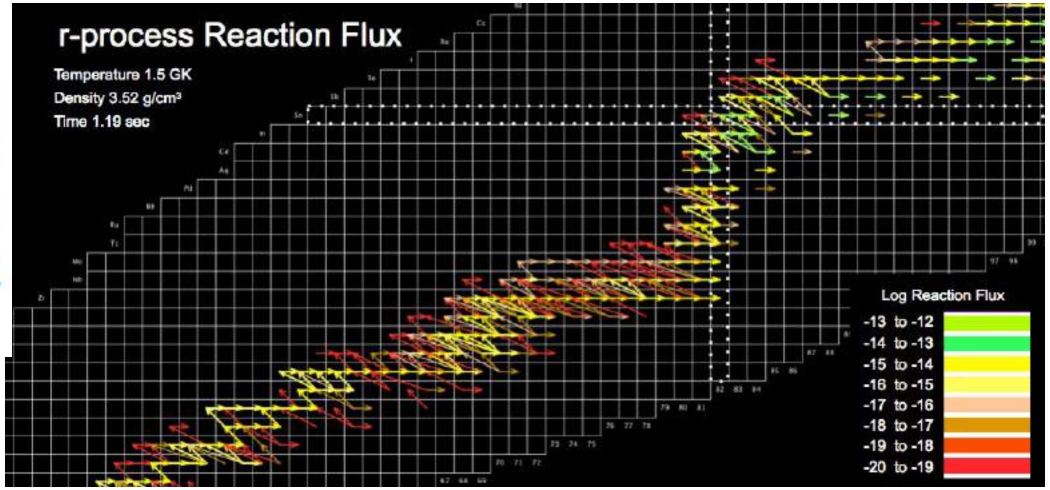




FRIB

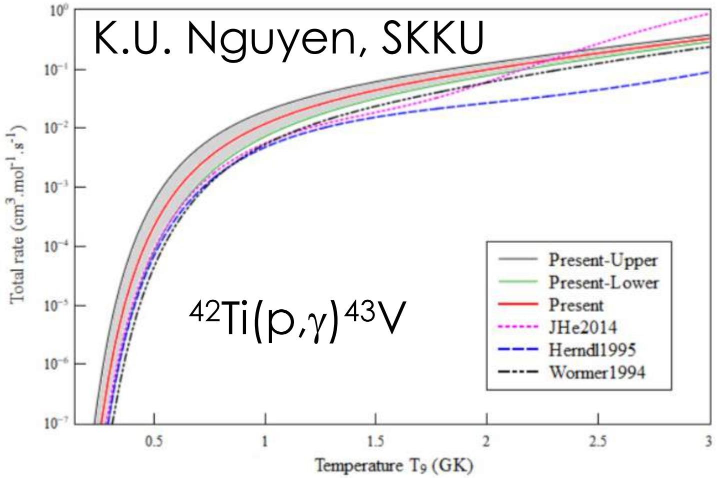


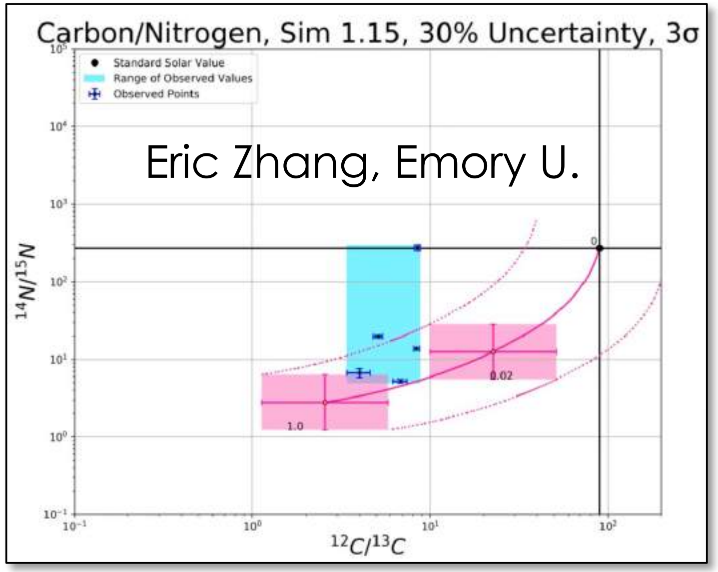




- focus on Stellar Explosions
- we **closely couple data activities to measurements** on unstable nuclei as recommended in NSAC LRP and listed as DOE NP milestones
- Personnel
  - *Michael Smith – Staff*
  - *Larry Zhang – Student*

Collaborators





- Beihang Univ. (BUAA) in Beijing, China
  - **Shisheng Zhang** (Professor) – theoretical nuclear physics, cross section predictions
  - **B. Shao**, **S. Y. Zhong**, **Sizhe Xu** (BUAA grad students) – theoretical nuclear physics
- SungKyunKwon Univ. (SKKU) in Korea
  - **Kyungyuk Chae** (Professor) – reaction assessments for astrophysics
  - **C. Kim** (postdoc), **K.U. Nguyen** (grad student) – reaction assessments for astrophysics
- Emory Univ. (Atlanta)
  - **Eric Zhang** (undergrad) – uncertainty quantification in nuclear astrophysics

Reaction Assessments

with SKKU

THE ASTROPHYSICAL JOURNAL, 929:96 (11pp), 2022 April 10 https://doi.org/10.3847/1538-4357/a

OPEN ACCESS

Estimation of the NiCu Cycle Strength and Its Impact on Type I X-Ray Bursts

Chanhee Kim[1], Kyungyuk Chae[1], Soomi Cha[2], Kyujin Kwak[3], Gwangeon Seong[3], and Michael Smith[4]
[1] Department of Physics, Sungkyunkwan University, Suwon 16419, Republic of Korea; kchae@skku.edu
[2] Center for Exotic Nuclear Studies, Institute for Basic Science (IBS), Daejeon 34126, Republic of Korea
[3] Department of Physics, School of Natural Science, Ulsan National Institute of Science and Technology (UNIST), Ulsan 44919, Republic of Korea
[4] Physics Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA
Received 2022 January 26; revised 2022 March 16; accepted 2022 March 16; published 2022 April 15

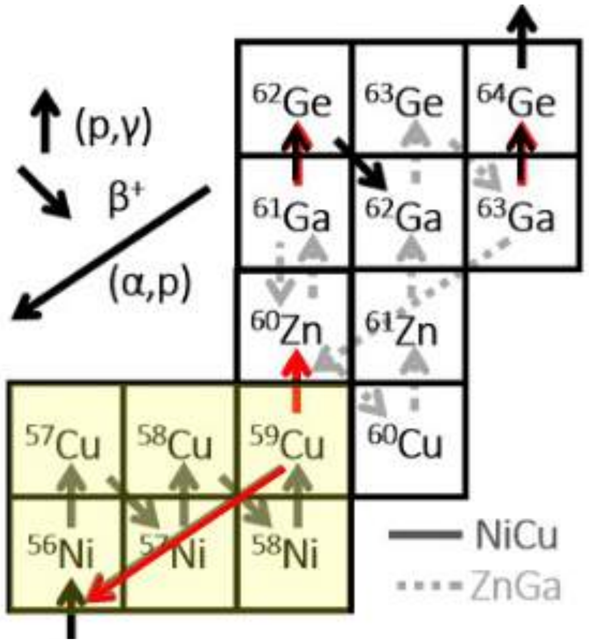
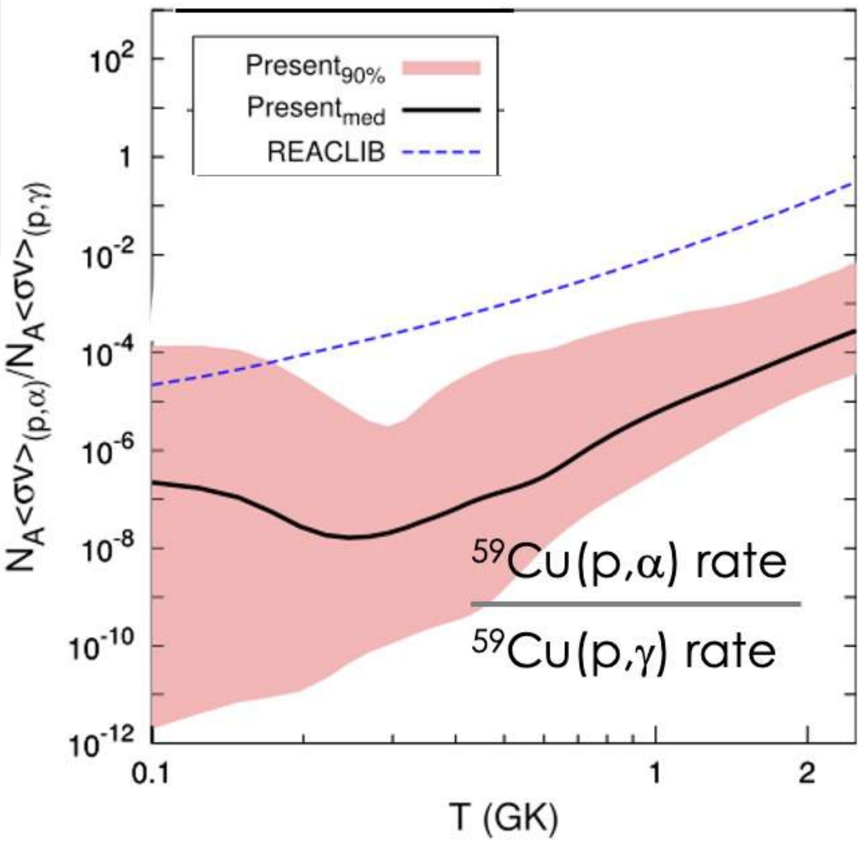


Figure 6. Strength of the NiCu cycle as a function of temperature (gigakelvin). The red band is obtained by setting the lower limit as the ratio of the low ^{59}Cu$(p,\alpha)^{56}$Ni and high ^{59}Cu$(p,\gamma)^{60}$Zn rates and the upper limit as the ratio of the high ^{59}Cu$(p,\alpha)^{56}$Ni and low ^{59}Cu$(p,\gamma)^{60}$Zn rates. The cycle strength by REACLIB and variations employed in the previous sensitivity studies are also plotted.



- Assessment of the ^{59}Cu(p,γ) and ^{59}Cu(p,α) rates for X-ray bursts

OAK RIDGE National Laboratory

Reaction Assessments

with SKKU

Assessment of the reaction rates of ^{42}Ti(p,γ)^{43}V in type I X-ray burst

N. K. Uyen, N. N. Duy and K. Y. Chae*

Department of Physics, Sungkyunkwan University, Suwon 16419, South Korea

M. S. Smith

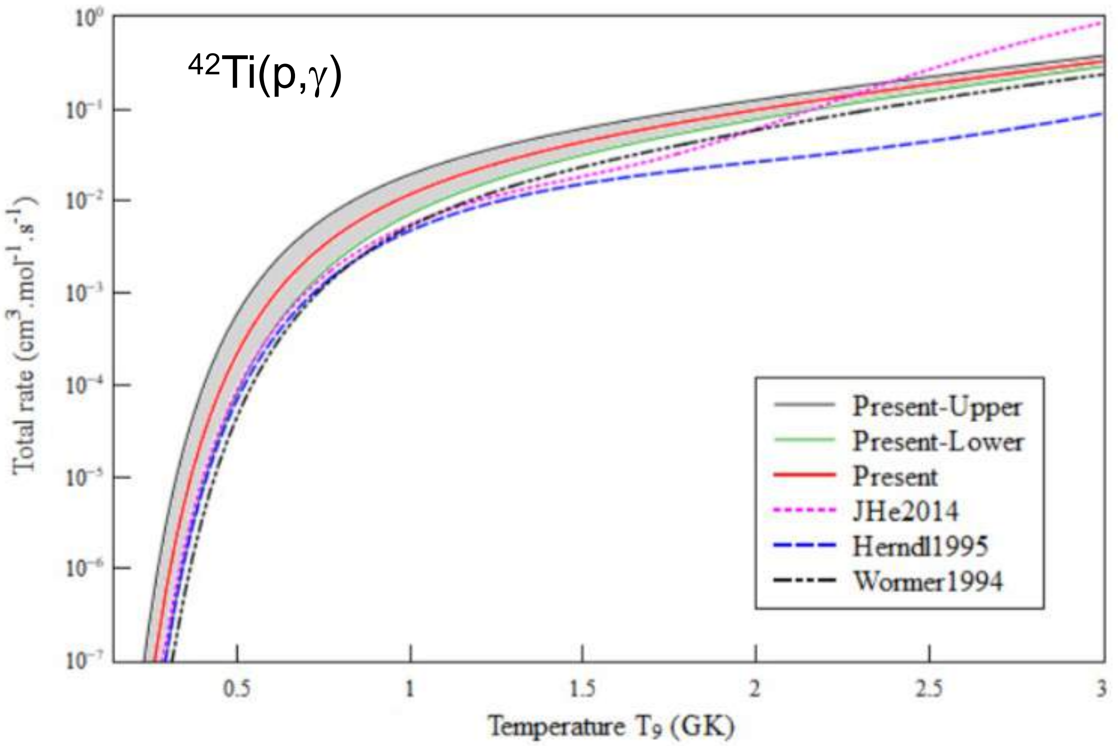
Physics Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA

L. Xayavong

Department of Physics, National University of Laos, 7322, Dongdok, Vientiane, Lao PDR

Table 2. The presently parameters for the ^{42}Ti$(\gamma,p)^{43}$V resonant reaction rates. The adopted proton separation energy $S_p = 100 \pm 43$ keV regarding to the AME16 relied on Ref. [16].

E_x (MeV)	E_i (MeV)	τ (ps)	J^π	l	C^2S_p	Γ_γ (eV)	Γ_p (eV)	$\omega\gamma$ (MeV)
0.436	0.336	22.00	$(\frac{5}{2})^-$	3	0.150	2.99×10^{-05}	1.73×10^{-08}	5.18×10^{-14}
0.537	0.437	117.00	$(\frac{3}{2})^-$	1	0.046	5.63×10^{-06}	1.09×10^{-04}	1.07×10^{-11}
1.014	0.914	9.14	$(\frac{3}{2})^-$	1	0.002	7.20×10^{-05}	6.07×10^{-02}	1.44×10^{-10}
1.844	1.744	0.61	$(\frac{3}{2})^-$	1	0.905	1.09×10^{-03}	$6.74 \times 10^{+03}$	2.17×10^{-09}



- Assessment of the ^{42}Ti(p,γ) rate for X-ray burst nucleosynthesis studies

Reaction Assessments

with SKKU

Chanhee Kim, K.Y. Chae et al. SKKU
M.S. Smith, K. Chipps, S.D. Pain, ORNL

PHYSICAL REVIEW C **105**, 025801 (2022)

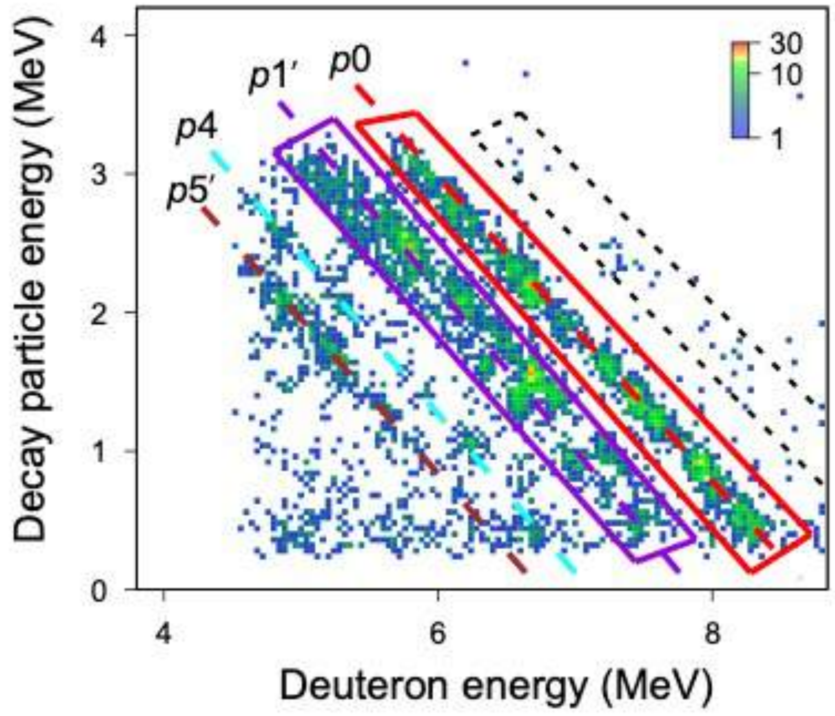


FIG. 1. Decay particle energy versus coincident reaction deuteron energy plot for all identified events. Four major diagonal bands labeled as $p0$, $p1'$, $p4$, and $p5'$ are evident. Each band

TABLE I. Proton branching ratios (b_p) of ^{23}Mg levels extracted for $p0$, $p1'$, $p1$, $p2$, and $p3$. The excitation energy values were taken from Ref. [20]. Uncertainties include factors originated from the statistics, backgrounds, and discrepancy between isotropic and anisotropic decay. See Sec. III C for detailed argument on isotropic and anisotropic decay.

E_x (keV)	b_{p0}	$b_{p1'}$	b_{p1}	b_{p2}	b_{p3}
8044 ± 4	0.36 ± 0.11				
8170 ± 4	0.36 ± 0.12				
8330 ± 6	0.48 ± 0.15				
8436 ± 7	0.59 ± 0.18				
8770 ± 8	0.86 ± 0.27				
8924 ± 5	0.47 ± 0.15	0.26 ± 0.08	(0.13 ± 0.04)	(0.01 ± 0.01)	(0.12 ± 0.04)
9123 ± 7	0.36 ± 0.11	0.35 ± 0.11	(0.06 ± 0.02)	(0.27 ± 0.09)	(0.03 ± 0.01)
9642	0.37 ± 0.11	0.49 ± 0.15	(0.14 ± 0.05)	(0.26 ± 0.08)	(0.08 ± 0.03)

- Measurement of branching ratio of ^{24}Mg(p,d)^{23}Mg levels for high-temp ^{22}Na(p,γ) burning

Nuclear Astrophysics Data

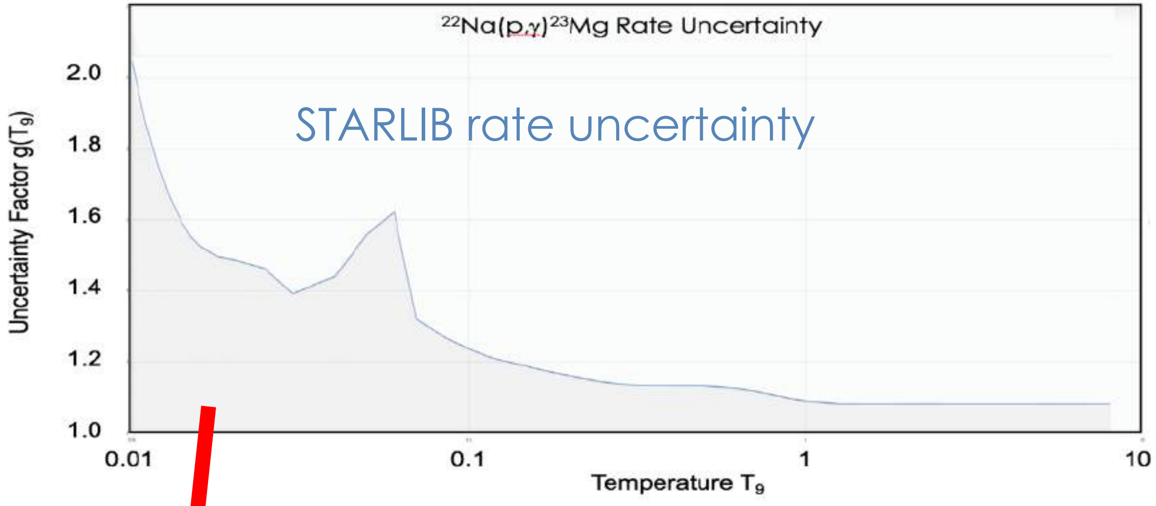
STARLIB rates

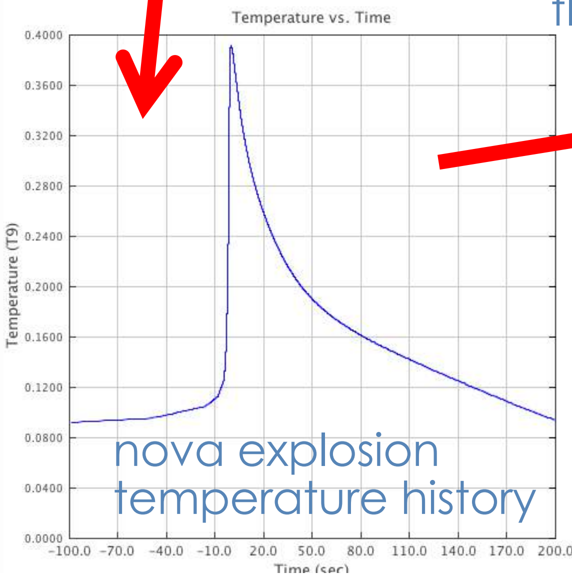
14C(a,g)18O
14C(p,g)15N
14N(a,g)18F
15N(a,g)19F
15O(a,g)19Ne
16O(a,g)20Ne
16O(p,g)17F
17F(p,g)18Ne
17O(p,a)14N
17O(p,g)18F
18F(p,a)15O
18F(p,a)15O
18F(p,g)19Ne
18O(a,g)22Ne
18O(p,a)15N

25Al(p,g)26Si
25Mg(p,g)26Al
26Al(p,g)27Si
26Mg(p,g)27Al
26Si(p,g)27P
27Al(p,a)24Mg
27Al(p,g)28Si
27P(p,g)28S
27Si(p,g)28P
28Si(p,g)29P
29P(p,g)30S
29Si(p,g)30P
30S(p,g)31Cl
30Si(p,g)31P
31Cl(p,g)32Ar

18O(p,g)19F
19Ne(p,g)20Na
20Ne(a,g)24Mg
20Ne(p,g)21Na
21Na(p,g)22Mg
21Ne(p,g)22Na
22Mg(p,g)23Al
22Na(p,g)23Mg
22Ne(p,g)23Na
23Al(p,g)24Si
23Mg(p,g)24Al
23Na(p,a)20Ne
23Na(p,g)24Mg
24Al(p,g)25Si
24Mg(a,g)28Si
24Mg(p,g)25Al

31P(p,a)28Si
31P(p,a)28Si
31P(p,g)32S
31S(p,g)32Cl
32Cl(p,g)33Ar
32S(p,g)33Cl
34Ar(p,g)35K
35Ar(p,g)36K
35Cl(p,a)32S
35Cl(p,g)36Ar
35K(p,g)36Ca
36Ar(p,g)37K
38Ar(p,g)39K
39Ca(p,g)40Sc
40Ca(p,g)41Sc



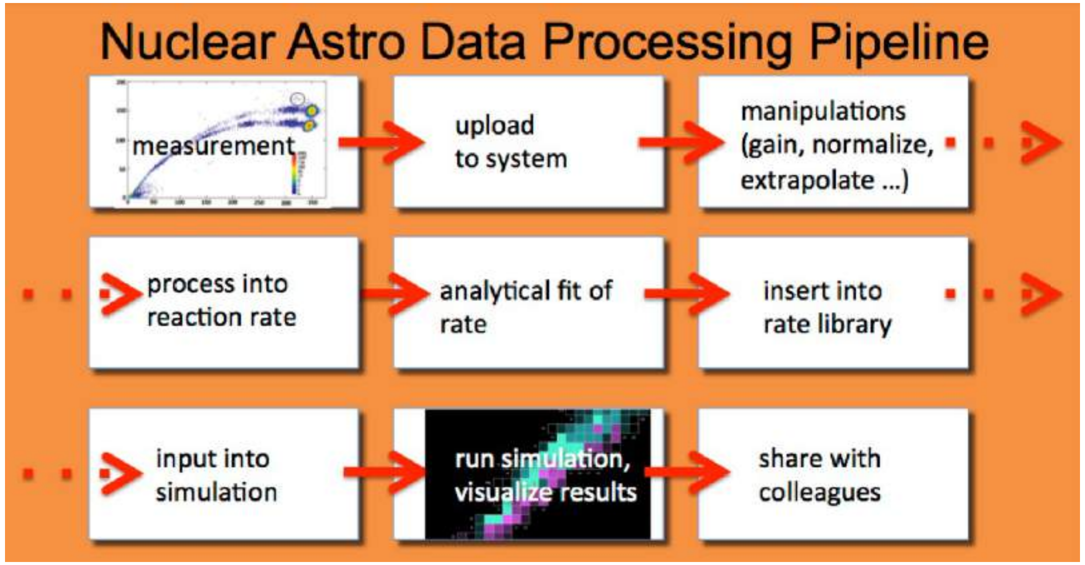


thermally avg uncertainty

Rate	Uncertainty Factor
n13 (p,g) o14	1.41
n14 (p,g) o15	1.08
n14 (a,g) f18	1.14
n15 (p,g) o16	1.42
n15 (a,g) f19	1.76
o15 (a,g) ne19	2.88
o16 (p,g) f17	1.07
o16 (a,g) ne20	1.41
o17 (p,g) f18	1.05
o18 (p,g) f19	1.34
o18 (a,g) ne22	2.08
. . .	. . .

- improving thermonuclear reactions
  - processing & thermally averaging rate uncertainties

Online Software Systems

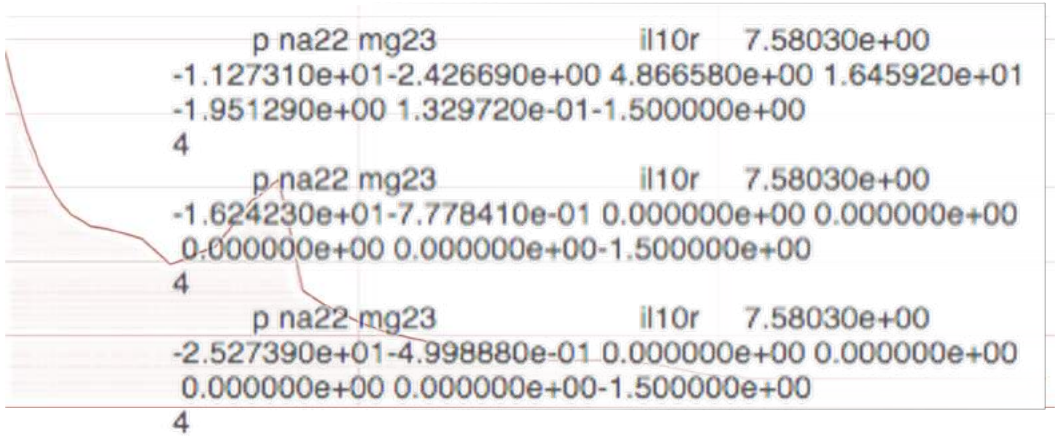


Computational Infrastructure for Nuclear Astrophysics

since 2004

- ***unique*** set of online software systems that **serve** the community carrying out DOE NP-supported research programs and endorsed by NSAC LRP
- systems used by researchers in over **180 institutions** in **42 countries**
- systems improve return on investment of **nuclear data for research projects**
- many ideas for expanding and improving these services
- currently working to improve the backbone of the system

Future Possible Projects



```
        p na22 mg23                      il10r     7.58030e+00
-1.127310e+01-2.426690e+00 4.866580e+00 1.645920e+01
-1.951290e+00 1.329720e-01-1.500000e+00
4
        p na22 mg23                      il10r     7.58030e+00
-1.624230e+01-7.778410e-01 0.000000e+00 0.000000e+00
 0.000000e+00 0.000000e+00-1.500000e+00
4
        p na22 mg23                      il10r     7.58030e+00
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 0.000000e+00 0.000000e+00-1.500000e+00
4
```
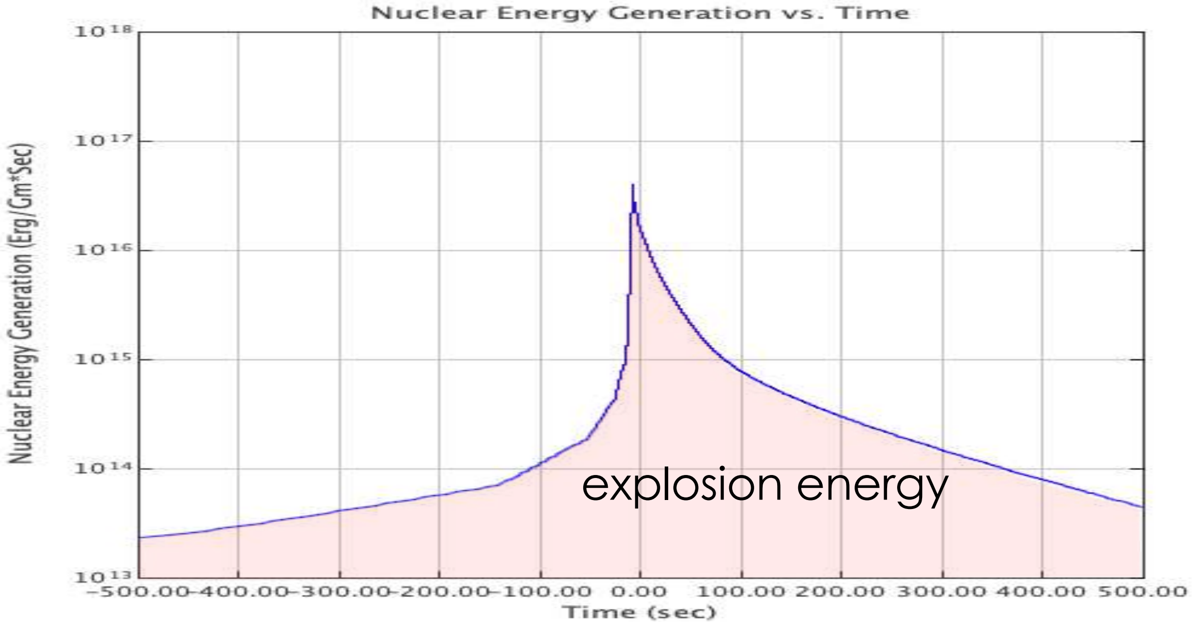
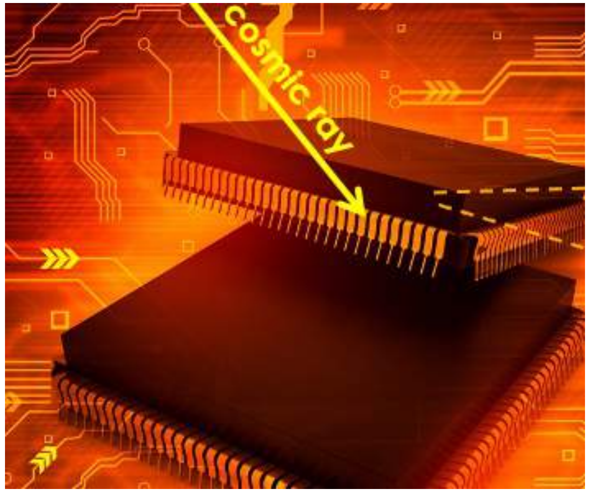
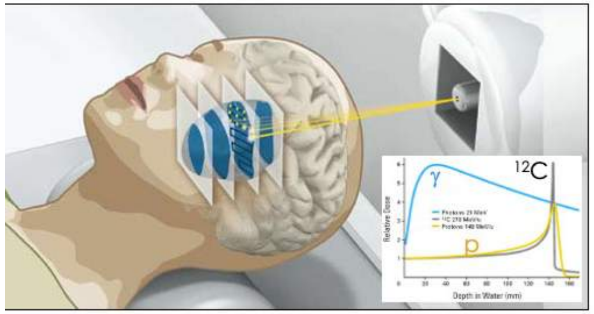



- add **uncertainties** to REACLIB thermonuclear rate library
- update REACLIB **content**
- develop **benchmark simulations** and **integral parameters** (*e.g.*, k_{eff} equivalents) to help validate nuclear astrophysics rate libraries
- explore processing (some) TALYS cross sections into REACLIB rate format

Synergistic Activities – WANDA2022

Workshop for Applied Nuclear Data Activities (WANDA 2022)

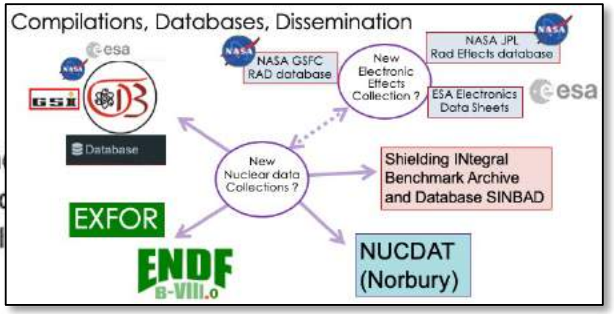




Nuclear Data for High Energy Ion Interactions and Secondary Particle Production

Chairs: K.LaBel (KBR Wyle/SSAI), M. Smith (ORNL), R. Vogt (LLNL/UC Davis)

Session Summary: The Galactic Cosmic Ray background covers a wide energy range, peaking at several hundred MeV/nucleon, but exten to and beyond 10 GeV/nucleon. The interaction of these particles with spacecraft materials and occupants creates a large and complex c that presents challenges to modeling, especially in the absence of measured data covering the entire energy range. In this session we wil identify the improvements required in all components of the nuclear data pipeline to enable safe space exploration.



- Organizer for **Space Session** on HE Ion Interactions/Secondary Particle Production
- Detailed Session report available on OSTI

Synergistic Activities – WANDA2022

Workshop for Applied Nuclear Data Activities (WANDA 2022)

Approved for public release. Distribution is unlimited

ORNL/TM-2022/2471

Nuclear Data for High Energy Ion Interactions and Secondary Particle Production

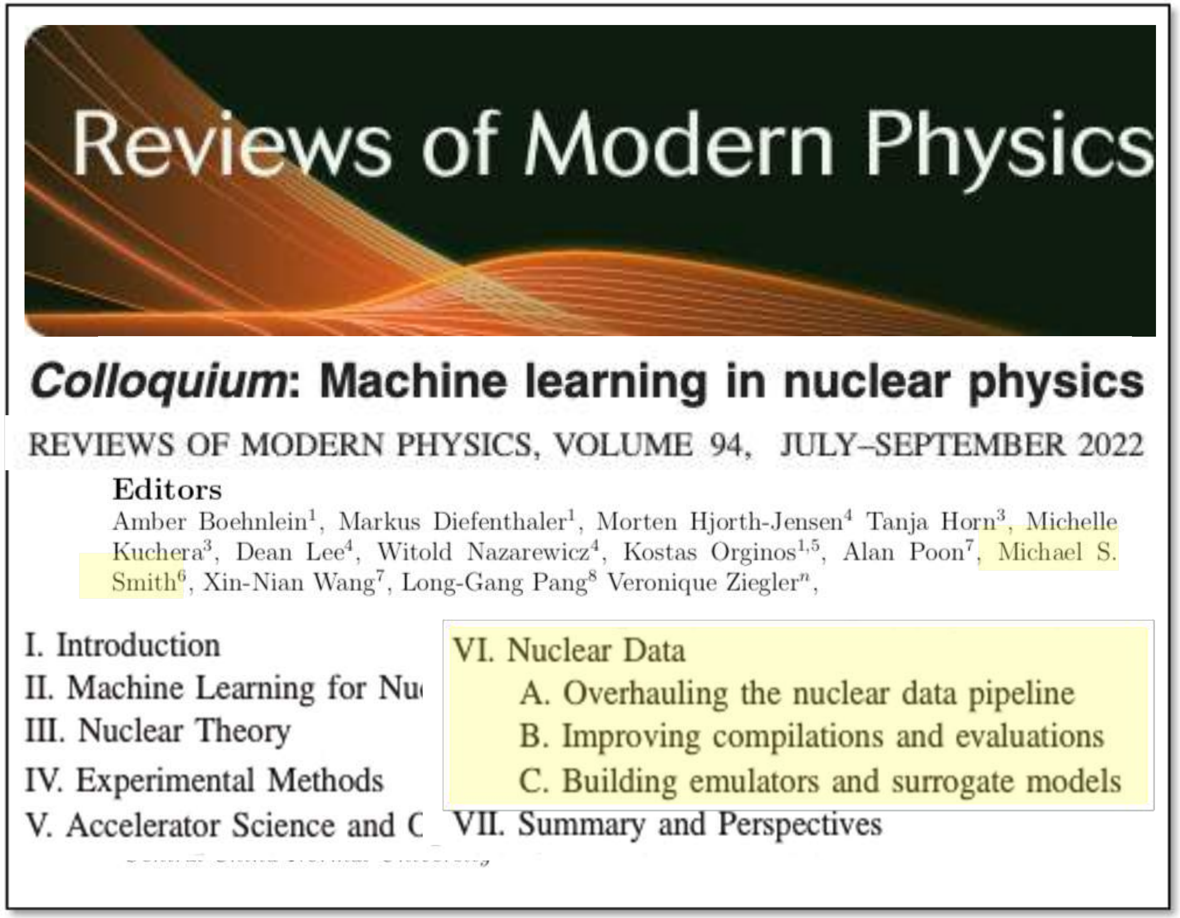
Michael S. Smith (ORNL)
Ramona Vogt (LLNL / UC Davis)
Ken LaBel (SSAI (NASA) and KBR Wyle (JHU/APL))

5/23/2022

- Organizer for **Space Session** on HE Ion Interactions/Secondary Particle Production
- Detailed Session report available on OSTI

Oak Ridge National Laboratory

Synergistic Activities – Machine Learning


Reviews of Modern Physics

Colloquium: Machine learning in nuclear physics

REVIEWS OF MODERN PHYSICS, VOLUME 94, JULY–SEPTEMBER 2022

Editors
Amber Boehnlein[1], Markus Diefenthaler[1], Morten Hjorth-Jensen[4] Tanja Horn[3], Michelle Kuchera[3], Dean Lee[4], Witold Nazarewicz[4], Kostas Orginos[1,5], Alan Poon[7], Michael S. Smith[6], Xin-Nian Wang[7], Long-Gang Pang[8] Veronique Ziegler[n],

I. Introduction
II. Machine Learning for Nu
III. Nuclear Theory
IV. Experimental Methods
V. Accelerator Science and C
VI. Nuclear Data
A. Overhauling the nuclear data pipeline
B. Improving compilations and evaluations
C. Building emulators and surrogate models
VII. Summary and Perspectives

USNDP Task Force on Machine Learning

- share approaches & algorithms
- plan strategies for future work
- create ML toolkits for non-experts
- collaborations with ML experts
- provide input for future FOAs
- recruit students/researchers

- co-author of RMP review article on **ML in Nuclear Physics**
- presentations on Machine Learning in Nuclear Data at NSAC Town Hall 2022
- Recommend formation of a **USNDP Task Force on Machine Learning**

Synergistic Activities – Outreach & Workforce

Informal Science Education and Career Advancement

Michael S. Smith,[1,*] Claudia Fracchiolla,[2,†] Sean Fleming,[3] Arturo Dominguez,[4] Alexandra Lau,[2] Shannon Greco,[4] Don Lincoln,[5] Eleni Katifori,[6] William Ratcliff,[7] Maria Longobardi,[8] Maajida Murdock,[9] and Mustapha Ishak[10]

This document supports a proposed APS statement that encourages academic, research, and other institutions to add the participation in informal science education activities to the criteria they use for hiring and career advancement decisions. There is a prevalent attitude that the time spent by a researcher on these activities takes time away from research efforts that are more valued by their peers and their institution. To change this mindset, we enumerate the many benefits of informal science education activities to the public, to researchers, to their institutions, and to the field of physics. We also suggest aspects of these activities that may be considered by institutions in evaluating informal educational efforts for recruitment and career advancement decisions.

arXiv:2112.10623v1

Outreach event with 6th graders in Rhode Island Nov 2022

- **Past Chair** of APS **Committee to Inform the Public** (CIP) – workforce development
- Elected to APS **Forum on Outreach and Engaging the Public** (FOEP)
- **Drafting poster** on Nuclear Data for DOE NP Office
- NSAC Town Hall presentations on **Outreach** and on **Education/Training**
- NSAC-ND subcommittee written input on **Workforce Retention**
- Remote **outreach presentations** on nuclear astrophysics & nuclear data given to middle school students in Rhode Island

Synergistic Activities – Outreach & Workforce

- **Drafting poster** on Nuclear Data for DOE NP Office