



The TREND update and Nuclear Data Needs for BNL

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TREND: <u>TR</u>i-lab <u>Effort on Nuclear Data</u>

Co-authors and collaborators

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Rationale

Knowledge energy dependent cross section is critical for:

- Accurate prediction of the yield of the isotope of interest
- Accurate prediction of radioisotopic impurities
- Defining the energy windows for optimum, cost-effective production of isotopes

It facilitates:

- Production planning
- Defining shielding requirements
- Transportation and shipment constraints

Bonus: comprehensive cross section data sets help constrain nuclear reaction models







Current state of the field

- Most of the data sets are limited to proton energy range up to 30 MeV
- A few more data sets are available up to 160 MeV
- Limited number of data sets are available up to 200 MeV

Approach

A tri-lab collaboration was formed to address the needs and cover proton energy range up to 200 MeV

- LBNL/UC Berkeley 0 55 MeV
- LANL 55 100 MeV
- BNL 100 200 MeV



Seeks to measure nuclear reaction cross sections for production of medically relevant (and other) isotopes and for beam monitor reactions

A comprehensive list of reactions was captured by Dr. François M. Nortier (Meiring) in 2017







Data sets of the primary focus

Priority	Isotope	Target	Incident particle	Measurement focus	Energy range	Years
1	⁷² Se, ⁶⁸ Ge	⁷⁵ As	р	Primary: ⁷² Se, ⁶⁸ Ge Impurities: ^{70,71,73,75} Se, ^{66,67,69,71} Ge	Up to 200 MeV	2019
2	¹¹⁹ Te, ^{117m} Sn	^{nat} Sb	р	Primary: ^{119m,119g} Te, ^{117m} Sn Impurities: ^{116,117,118,121m,121g,123m} Te, ^{113,119m,121m,121g} Sn	Up to 200 MeV	2020-21
3	²⁰² Pb	nat T 	р	Primary: ^{202m,202g} Pb Impurities: ^{198,199,200,201,203,204,205} Pb	Up to 200 MeV	2022
4	¹³⁴ Ce	^{nat} La	р	Primary: ¹³⁴ Ce Impurities: ^{132,133,133,137,139} Ce	50-200 MeV	2023







Experimental: stacked foil technique

- Irradiate array of target and monitor foils with known thickness/areal density intermixed with degraders
 - Very low current 100-200 nA
- Use gamma spectroscopy to count each foil individually
 - Multiple spectra collection allows for accurate error characterization
- Determine activity of <u>all</u> produced radionuclides
- Use activation equation to solve for σ for each individual foil

Dr. Jonathan Morrell developed Python based code (Curie)* which performs gamma spectra fitting and decay routine that is used for data analysis

*J. T. Morrell, Curie: Python Toolkit for Experimental Nuclear Data (2020).











Facilities

- LBNL operates 88-inch cyclotron
 - Both light- and heavy-ion capabilities.
 - Protons and other light-ions are available at intensities (10-20 pA)
 - Maximum energies of 60 MeV (protons), 65 MeV (deuterons), 170 MeV (³He), and 130 MeV (⁴He).
 - BLIP (BNL) and IPF (LANL) share conceptually similar design
 - Operate of LINACs
 - IPF max accepted proton energy 100 MeV, max current 350 μA
 - BLIP max energy 200 MeV, incrementally tunable, max current 200 µA
 - Designed for large scale isotope production





ational Laboratory



BLIP SCHEMATIC **Brookhaven Linac Isotope Producer (BLIP) target** Ground HOT CELLstation level LEAD -// 12 3/4" O.D. STEEL **18" POLYETHYLENE** Located 30 feet below ground lével to **INSPECTION PORT** BEADS the bottom of the water shaft LACE FR CONCRETE SHIELD PLUG 18" STEEL SHOT Targets delivered to and retrieved from the beamline using chain drive 18" O.D. STEEL SHAFT 16" O.D. STAINLESS STEEL system (SAND CONTAINMENT) CONTAINMENT SHAFT (FILLED WITH WATER) About 6 inches (152.4 mm) of space SAND available along the beam pass for target positioning EXISTING BLIP TANK 8'- 0" DIA, x 30'- 4" LONG Incrementally tunable LINAC energy: 200, 180, 160, 140, 117, 66 MeV SHIELD (SAND) SUPPORT STRUCTURE Rastered and focused beam pattern Multiple targets arranger stacked one TARGETS LINAC after another BEAM TUNNEL -FLOOR rookhaven





IPF

Experimental: stacked foils for irradiation

BLIP





LBNL







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Morgan Fox LBNL











LBNL

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Figure 1. Preliminary measurement of the ¹³⁹La(p,x)¹³⁴Ce reaction cross section, from the Sep. 22 experiment at LANL IPF, plotted against existing measurements and several modeling codes (using default parameters).







Implications for isotope production

- Reactions on arsenic: first data set for ^{nat}As(p,x) ⁶⁸Ge reaction up to 200 MeV revealed opportunities for Ge-68 production with medium to high energy protons
 - Lower thermal load on the target at higher energy
 - No interference with medium energy production targets at BLIP

Reactions on antimony:

- Control of co-production of long-lived Sn-113 impurity
- Better understanding of energy resolution for Te-118 and Te-119

Te 6.00	115 ^{7/+}) m	Te 116 149 m	Te 117 ^{1/+} 65.0 m	Te 118 6.00 d	^{11/-} Te 4.68 d	119 ^{1/+} 16.0 h	Te 120 0.096	^{11/} Te 154 d	121 ^{1/+} 16.8 d	Te 122 26.000	^{11/-} Te	123 ^{1/+} 0.905 1.2E13 a	Te 124 4.816
							σ _{2.00}			σ2.00, 80.0		σ _{420,} 5800	σ7.00, 5.00
E4	.64	E 1.50	E 3.54	E.278		E 2.29	119.904026		E 1.04	121.903056	122.9	04271	123.902819
Sb 3.4	114 ³⁺ 5m	Sb 115 5/+ 31.8 m	⁸⁻ Sb 116 ³⁺ 60.3 m 15.8 m	Sb 117 5/+ 2.80 h	⁸⁻ Sb 5.00 h	118 ¹⁺ 3.60 m	Sb 119 5/+ 38.5 h	⁸⁻ Sb 5.80 d	120 ¹⁺ 15.9 m	Sb 121 5/4 57.300	⁽⁸⁾⁻ Sb 4.20 m	122 ²⁻ 64.8 h	Sb 123 7/+ 42.700
										σ 6.33, 209			σ _{4.08, 118}
E 5	.88	E 3.03	E 4.71	E 1.76		E 3.66	E .594		E 2.68	120.903822		E 1.98	122.904216
^{7/+} Sn 20.0 m	113 ^{1/+} 115 d	Sn 114 0.650	Sn 115 ^{1/+} 0.360	Sn 116 14.530	^{11/-} Sn 14.0 d	117_1/+ 7.680	Sn 118 24.220	^{11/-} Sn 245 d	119 ^{1/+} 8.580	Sn 120 32.590	^{11/-} Sn 50.0 a	121 ^{3/+} 27.0 h	Sn 122 4.630
		σ 100mb, 5.00	σ30.0, 30.0	σ _{100mb} , 11.0		σ _{1.30,}			σ _{2.00,} 4.00	σ _{160mb, 1.20}			σ _{2.00mb}
	E 1.04	113.902783	114.903348	115.901746	116.9	02955	117.901608	118.9	03310	119.902199		E.388	121.903441







Implications for isotope production

• **Reactions of thallium**: comprehensive data sets on thallium will constrain Talys prediction of difficult to measure Pb-202 and Pb-205

Pb 200 21.5 h	^{13/+} Pb 201 ^{5/-} 61.0 s 9.4 h	⁹ <u>Pb 202</u> 3 62 h 3.0E5 a	^{13/+} Pb 203 5/ 6.20 s 52.1 h	⁹⁻ Pb 204	Pb 205 5/- 1.4E7 a	Pb 206 24.100
				69.0 m 1.4E17 a		
E 810	5100	E 050	E 975	σ _{660mb} , 2.00	E 051	σ 30.0mb, 100mb
T1 199 ^{1/4} 7.40 h	T1 200 ²⁻ 26.1 h	T1 201 ^{1/4} 73.5 h	T1 202 ²⁻ 12.2 d	T1 203 1/4 29.520	T1 204 ²⁻ 3.78 a	T1 205 1/4 70.480
				σ 11.4, 41.0		σ 100mb, 700mb
E 1.44	E 2.46	E.483	E 1.36	202.972328	E .764	204.974412

 Reactions on lanthanum: control of the impurities in production of Ce-134

	Ce 134 72.0 h	^{11/(·)} Ce 135 ^{1/(+)} 20.0 s 17.6 h	Ce 136 0.190	^{11/-} Ce 137 ^{3/+} 34.4 h 9.00 h	Ce 138 0.250	^{11/-} Ce 139 ^{3/+} 56.2 s 138 d	Ce 140 88.480
			σ 6.30, 70.0		σ1.10, 7.00		σ 575mb, 480mb
-	E.500 E2.03 La 133 ^{5/+} La 134 ¹⁺ 3.91 h 8.67 m		La 135 5/4 19.5 h	La 136 ¹⁺ 9.9 m	La 137 7/+ 6.0E4 a	La 138 ⁵⁺ 0.090 1.4E11 a	139.905435 La 139 ^{7/+} 99.910
	E2.23 E3.71		E 1.20	E 2.87	E.600	σ 57.0, 400 137.907107	σ _{9.34, 11.6} 138.906349







BLIP nuclear data needs

- BLIP receives 200 MeV protons: this energy has to be absorbed either by degraders or production targets
- Cross section data sets with improved uncertainties are necessary for design of both targets and degraders
- Data sets for production for energies from 100-200 MeV are of particular importance at BLIP to improve economics of production
- Cross section data sets for fast neutrons are of
 importance due to substantial flux of secondary neutrons







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- LBNL is managed by University of California for US DOE Office of Science



• Los Alamos The Tri-lab Nuclear Data Collaboration







Not Pictured: Lee Bernstein (LBNL) Eva Birnbaum (LANL) Cathy Cutler (BNL)



