LANL Light Element Evaluations

in Nuclear Security, Energy, Safety & Science

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Workshop for Applied Nuclear Data Applications

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Overview

- **LANL provides most of the existing ENDF light element evaluations**
  - "Light elements" mean less than ~20 nucleons
  - **Essential for actinide evaluations and these *should be done concurrently***
  - LANL R-matrix analysis code "EDA"
    - **Large code-modernization effort: higher energies, charged-particle, break-up reactions**
  - ***ALL*** available data is analyzed
    - **Neutron & charged-particle induced**
    - **ALL scattering & reactions (direct, compound, transfer, break-up, ...)**
    - **Unpolarized & polarized**
- ***End-user applications*:**

Light-element data relevant for most applications

  - Most of the state-of-the-art ENDF/B-VIII.0 light-element evaluations were done at LANL by **Gerry Hale** and collaborators
  - **Nuclear security**: thermonuclear fusion; TN boost & burn; ...
  - **Nuclear energy**: inertial & magnetic confinement fusion; plasma-nuclear interactions
  - **Nuclear safety**: Criticality Safety Project (important elements: H, Li, C, O,...)
  - **Basic & applied nuclear science**: nuclear & particle physics, astrophysics, cosmology

LANL-EDA evaluation capabilities

- **R-matrix formalism [Wigner(1947)]**
  - Unified description of many reactions
  - Fully quantum-theoretic approach
- **Capabilities**
  - Any projectile: n, p, D, T, ^{3}He, α, …
  - Any target: H, He, Li, Be, B, C, N, O, F, …
  - All data fit ***together, at the same time***
    - Elastic, inelastic, rearrangement, breakup, capture
  - All observables
    - Cross sections: elastic, reaction, total
    - Angular distributions/excitation functions
    - Polarization observables
    - Break-up spectra: 2➔3- & 4-body
    - Capture/electromagnetic
  - Covariance/uncertainty information generated
- **High-fidelity fit:**
  - Typical chi-squared: χ^2/dof ~ 1.2 – 1.5

Channel	a_c (fm)	l_{max}
t+^{4}He	4.02	5
n+^{6}Li	5.0	3
n+^{6}Li*	5.5	1
d+^{5}He	6.0	0

Reaction	Energy Range (MeV)	# Pts.	Observables
^{4}He(t,t)^{4}He	E_t=0 - 14	1661	σ(θ), $A_y(t)$
^{4}He(t,n)^{6}Li	E_t = 8.75 - 14.4	37	σ_{int}, σ(θ)
^{4}He(t,n)^{6}Li*	E_t =12.9	4	σ(θ)
^{6}Li(n,t)^{4}He	E_n = 0 - 4	1406	σ_{int}, σ(θ)
^{6}Li(n,n)^{6}Li	E_n = 0 - 4	800	σ_T, σ_{int}, σ(θ), $P_y(n)$
^{6}Li(n,n')^{6}Li*	E_n = 3.35 - 4	8	σ_{int}
^{6}Li(n,d)^{5}He	E_n = 3.35 - 4	2	σ_{int}
Total		3918	13

- **Unified, simultaneous fit**
  - describe all data together
  - fit quantum mechanical amplitudes, not cross sections
- **Built-in Quality Assurance**
  - Normalization constrained
    - Weed-out underestimated exp'l uncertainties
- ***Superior to single-channel or polynomial fitting***

Status of existing LANL evaluations ENDF/B-VIII.0

Highlights

1. p+t, p+^{3}He, p+^{6,7}Li
2. d+d, d+t, d+^{3}He
3. t+t, t+^{6}Li
4. n+^{6}Li, n+^{12}C, n+^{13}C
5. ^{9}Be system
6. ^{15}N system
7. n+^{16}O

Ongoing work:

- *Code modernization*
- *Interface EDA evaluation*
  NJOY, MCNP, weapons application codes, ...
- *Toward global evaluations*
  Allow concurrent evaluations of light/heavy/benchmarking

Existing LANL evaluations

A	System	Channels	Energy Range (MeV)
2	N-N	p+p; n+p, γ+d	0-40 0-40
3	N-d	p+d; n+d	0-4
4	^{4}H; ^{4}Li	n+t; p+^{3}He	0-20
	^{4}He	p+t; n+^{3}He; d+d	0-11; 0-10; 0-10
5	^{5}He	n+α; d+t; ^{5}He+γ	0-28; 0-10
	^{5}Li	p+α; d+^{3}He	0-24; 0-1.4

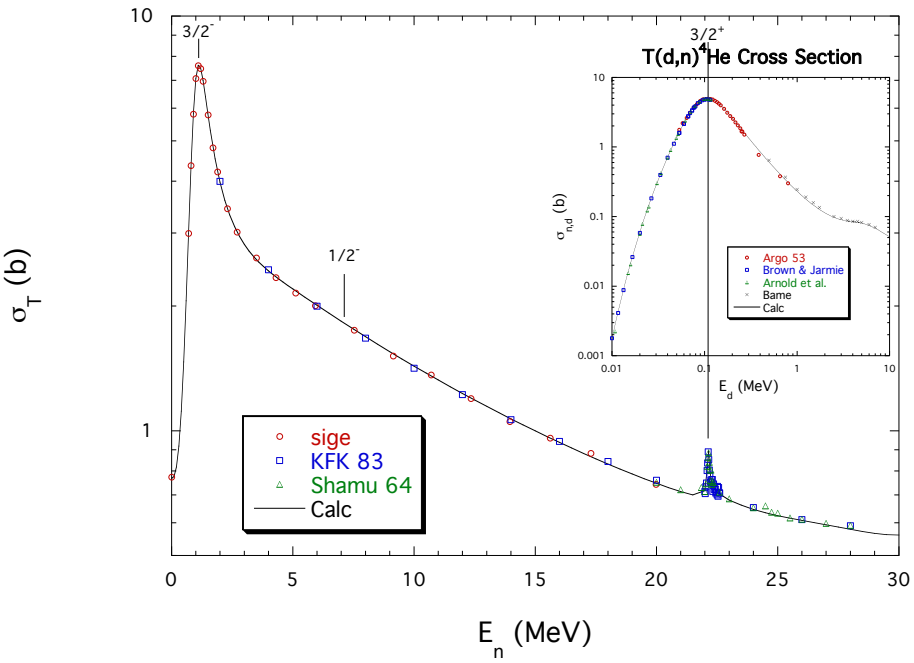
A	System (Channels)
6	^{6}He (^{5}He+n, t+t); ^{6}Li (d+^{4}He, t+^{3}He); ^{6}Be (^{5}Li+p, ^{3}He+^{3}He)
7	^{7}Li (t+^{4}He, n+^{6}Li); ^{7}Be (γ+^{7}Be, ^{3}He+^{4}He, p+^{6}Li)
8	^{8}Be (^{4}He+^{4}He, p+^{7}Li, n+^{7}Be, p+^{7}Li*, n+^{7}Be*, d+^{6}Li)
9	^{9}Be (^{8}Be+n, d+^{7}Li, t+^{6}Li); ^{9}B (γ+^{9}B, ^{8}Be+p, d+^{7}Be, ^{3}He+^{6}Li)
10	^{10}Be (n+^{9}Be, ^{6}He+α, ^{8}Be+nn, t+^{7}Li); ^{10}B (α+^{6}Li, p+^{9}Be, ^{3}He+^{7}Li)
11	^{11}B (α+^{7}Li, α+^{7}Li*, ^{8}Be+t, n+^{10}B); ^{11}C (α+^{7}Be, p+^{10}B)
12	^{12}C (^{8}Be+α, p+^{11}B)
13	^{13}C (n+^{12}C, n+^{12}C*)
14	^{14}C (n+^{13}C)
15	^{15}N (p+^{14}C, n+^{14}N, α+^{11}B)
16	^{16}O (γ+^{16}O, α+^{12}C)
17	^{17}O (n+^{16}O, α+^{13}C)
18	^{18}Ne (p+^{17}F, p+^{17}F*, α+^{14}O)

Thank you!

Follow-on material

T(d,n)α evaluation (I)

- **Simultaneously fits all known low-E data**
  - neutron & charged-particle channels
  - polarization (distinguishes partial waves, etc.)
- **High-fidelity X^2 ~ 1.5 below 10 MeV**
- **All resonances/partial waves included**
- **EDA also provides covariance matrices**

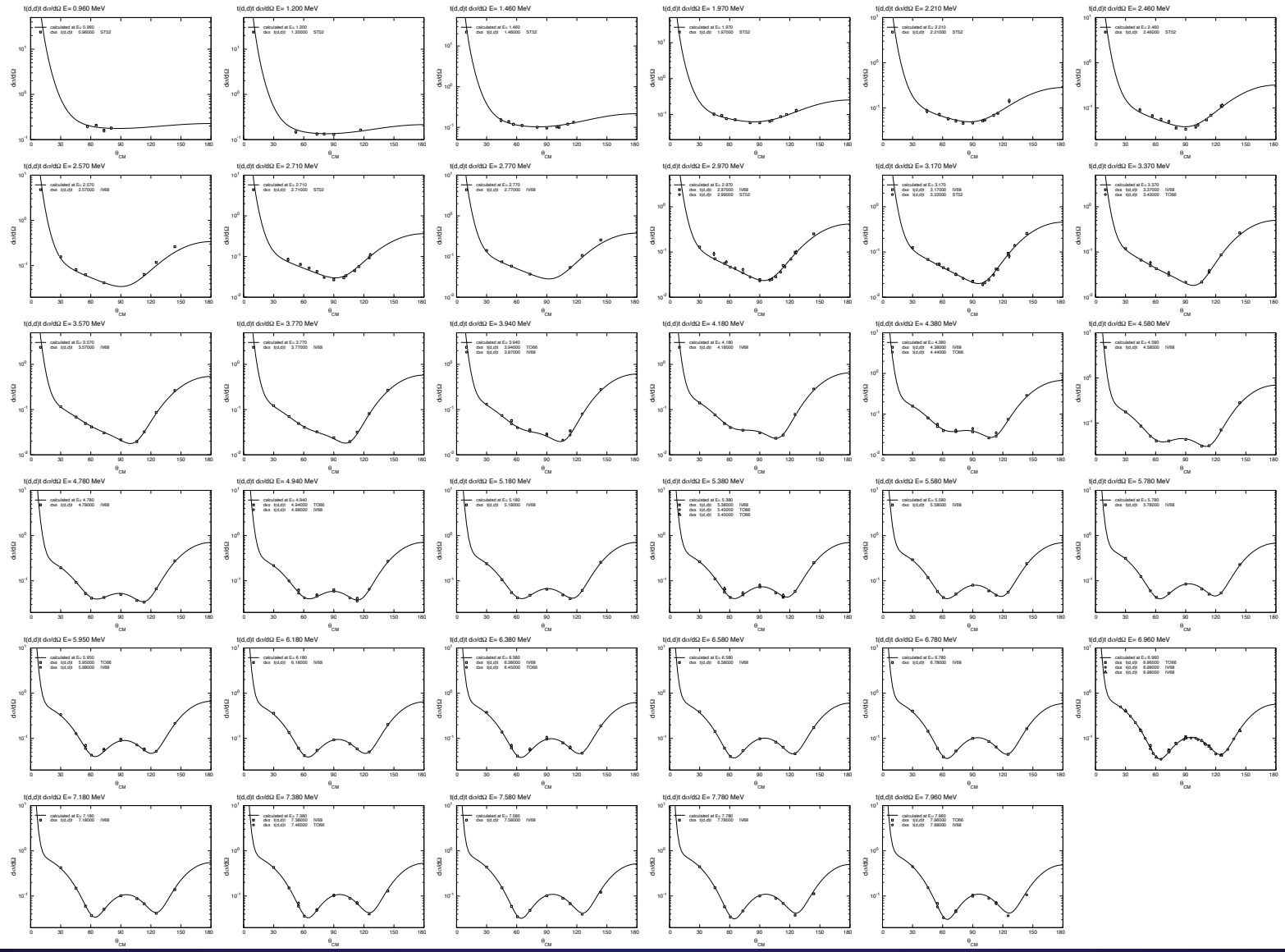


channel	a_c (fm)	l_{max}
n+^{4}He	3.0	5
γ+^{5}He	60	1
d+^{3}H	5.1	5
n+^{4}He*	5.0	1

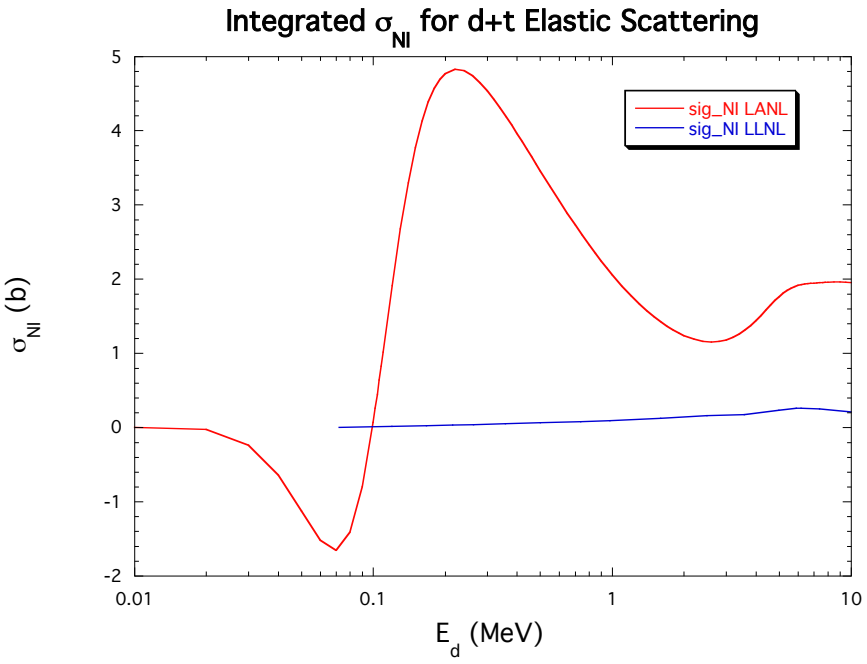
Reaction	Energies (MeV)	# data points	# data types
^{4}He(n,n)^{4}He	E_n = 0 – 40	817	2
^{3}H(d,d)^{3}H	E_d = 0 – 8.6	700	6
^{3}H(d,n)^{4}He	E_d = 0 – 30	1185	14
^{3}H(d,γ)^{5}He	E_d = 0 – 8.6	17	2
^{3}H(d,n)^{4}He*	E_d = 4.8 – 8.3	10	1
total		2729	25

T(d,n)α evaluation (II)

Angular distributions T(d,el)



T(d,n)α evaluation (II)
σ_{NI} T(d,el) nuclear plus interference



- **Nuclear + interference cross section**
  - requires multichannel fit
  - strong energy dependence
  - not necessarily > 0

Status of existing LANL evaluations ENDF/B-VIII.0

Neutron induced

```
==> neutrons-VIII_0_owners.txt <==
 0 - N - 1 LANL        EVAL-APR16 HALE, PARIS                          25 1451
  1-H -  1 LANL        EVAL-JUL16 G.M.Hale                            125 1451
  1-H -  2 LANL        EVAL-FEB97 P.G.Young,G.M.Hale,M.B.Chadwick     128 1451
  1-H -  3 LANL        EVAL-NOV01 G.M.Hale                            131 1451
  2-He-  3 LANL        EVAL-MAY90 G.Hale,D.Dodder,P.Young             225 1451
  2-He-  4 LANL        EVAL-SEP10 Hale                                228 1451
  3-Li-  6 LANL        EVAL-JAN17 G.M. Hale                           325 1451
  3-Li-  7 LANL        EVAL-AUG88 P.G.Young                           328 1451
  4-Be-  7 LANL        EVAL-JUN16 I.Thompson, P.R.Page                419 1451
  4-Be-  9 LLNL,LANL   EVAL-OCT09 G.HALE,PERKINS ET AL,FRANKLE        425 1451
  5-B - 10 LANL        EVAL-FEB17 G.M.Hale                            525 1451
  5-B - 11 LANL        EVAL-MAY89 P.G.Young                           528 1451
  6-C - 12 LANL,ORNL   EVAL-AUG15 G.M. Hale, P.G. Young, C.Y. Fu      625 1451
  6-C - 13 LANL,       EVAL-AUG15 G.M. Hale, M.W. Paris               628 1451
  7-N - 14 LANL        EVAL-JUN97 M.B.Chadwick,P.G.Young              725 1451
  7-N - 15 LANL        EVAL-SEP83 E.Arthur,P.Young,G.Hale             728 1451
  8-O - 16 LANL        EVAL-DEC16 Hale,Paris,Young,Chadwick           825 1451
```

ENDF/B-VIII.0 evaluation custodians

```
==> alphas-VIII_0_owners.txt <==
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==> deuterons-VIII_0_owners.txt <==
  1-H -  2 LANL       EVAL-SEP01 G.M.HALE                          128 1451
  1-H -  3 LANL       EVAL-JAN95 G.M.HALE  AND M.DROSG             131 1451
  2-He-  3 LANL       EVAL-FEB01 G.M.HALE                          225 1451
  3-Li-  6 LANL       EVAL-JUN04 P.R.PAGE                          325 1451
  3-Li-  7 LLNL       EVAL-NOV10 P. Navratil, D. A. Brown          328 1451
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  2-He-  4 LLNL       EVAL-DEC99 R.M.White,D.A.Resler,S.I.Warshaw  228 1451
  3-Li-  6 LANL       EVAL-NOV02 G.M.HALE                          325 1451
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  1-H -  1 LANL       EVAL-JUL16 G.M.Hale                          125 1451
  1-H -  2 LANL       EVAL-FEB97 P.G.Young,G.M.Hale,M.B.Chadwick   128 1451
  1-H -  3 LANL       EVAL-NOV01 G.M.Hale                          131 1451
  2-He-  3 LANL       EVAL-MAY90 G.Hale,D.Dodder,P.Young           225 1451
  2-He-  4 LANL       EVAL-SEP10 Hale                              228 1451
  3-Li-  6 LANL       EVAL-JAN17 G.M. Hale                         325 1451
  3-Li-  7 LANL       EVAL-AUG88 P.G.Young                         328 1451
  4-Be-  7 LANL       EVAL-JUN16 I.Thompson, P.R.Page              419 1451
  4-Be-  9 LLNL,LANL  EVAL-OCT09 G.HALE,PERKINS ET AL,FRANKLE      425 1451
  5-B - 10 LANL       EVAL-FEB17 G.M.Hale                          525 1451
  5-B - 11 LANL       EVAL-MAY89 P.G.Young                         528 1451
  6-C - 12 LANL,ORNL  EVAL-AUG15 G.M. Hale, P.G. Young, C.Y. Fu    625 1451
  6-C - 13 LANL,      EVAL-AUG15 G.M. Hale, M.W. Paris             628 1451
  7-N - 14 LANL       EVAL-JUN97 M.B.Chadwick,P.G.Young            725 1451
  7-N - 15 LANL       EVAL-SEP83 E.Arthur,P.Young,G.Hale           728 1451
  8-O - 16 LANL       EVAL-DEC16 Hale,Paris,Young,Chadwick         825 1451
```

ENDF/B-VIII.0 evaluation custodians (cont.)

```
==> protons-VIII_0_owners.txt <==
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  1-H -  2 LANL       EVAL-FEB97 P.G.YOUNG,G.M.HALE,M.B.CHADWICK     128 1451
  1-H -  3 LANL       EVAL-SEP01 G. M. HALE                          131 1451
  2-He-  3 LANL       EVAL-OCT83 G.HALE                              225 1451
  2-He-  4 LLNL       EVAL-DEC99 R.M.White,D.A.Resler,S.I.Warshaw    228 1451
  3-Li-  6 LANL       EVAL-AUG01  G.M.HALE                           325 1451
  3-Li-  7 LLNL       EVAL-SEP10 P. Navratil, D.A. Brown             328 1451
  4-Be-  9 LANL       EVAL-NOV88 P.G.Young, E.D.Arthur               425 1451
  5-B - 10 LANL       EVAL-AUG05   P.R.PAGE                          525 1451
  6-C - 12 LANL       EVAL-JUN96 M.B.CHADWICK AND P.G.YOUNG          625 1451
  6-C - 13 LANL       EVAL-DEC04  P.R.PAGE                           628 1451
  7-N - 14 LANL       EVAL-AUG97 M.B.CHADWICK & P.G.YOUNG            725 1451
  8-O - 16 LANL       EVAL-JUN96 M.B.CHADWICK AND P.G.YOUNG          825 1451
==> tritons-VIII_0_owners.txt <==
  1-H -  3 LANL       EVAL-FEB01 G.M.HALE                            131 1451
  2-He-  3 LANL       EVAL-AUG01 G.M.HALE                            225 1451
  2-He-  4 LLNL       EVAL-DEC99 R.M.White,D.A.Resler,S.I.Warshaw    228 1451
  3-Li-  6 LANL       EVAL-SEP01 G.M.HALE                            325 1451
  3-Li-  7 LLNL       EVAL-JUN16 I.Thompson, P.Navratil, D.Brown     328 1451
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^{6}Li

deuterons, neutrons