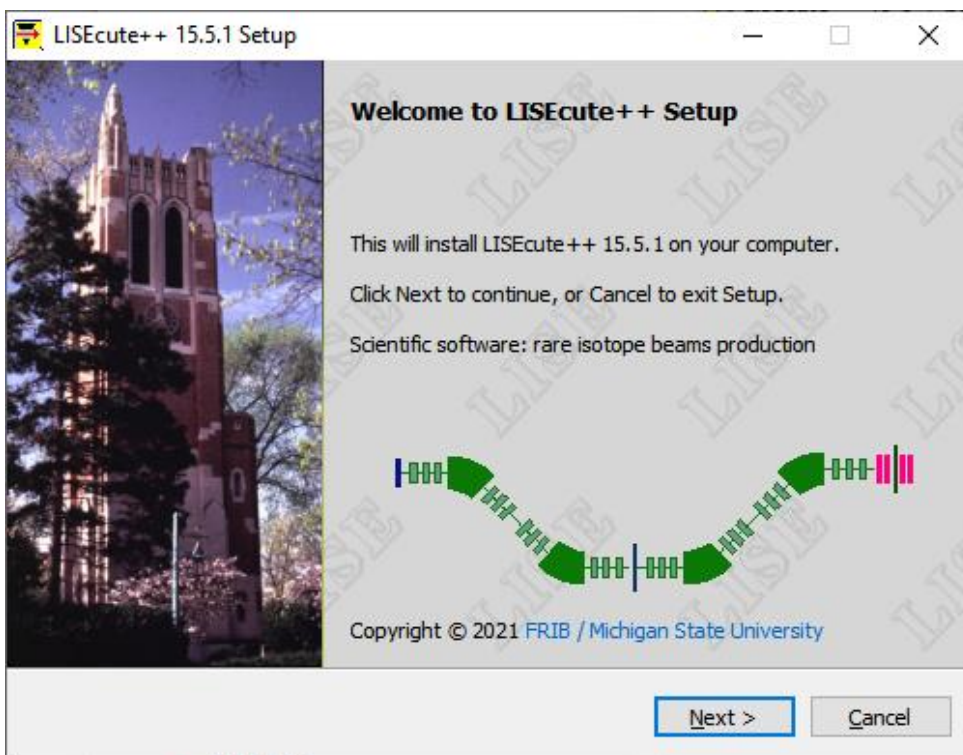


Oleg B. Tarasov,

FRIB / MSU

*@ Workshop for Applied
Nuclear Data Activities
(WANDA 2021)*



Contents

- ❖ Introduction
 - LISE⁺⁺ Package
 - Fragment-separator construction
 - Reaction Mechanisms
 - Application

- ❖ Databases in LISE⁺⁺
 - Masses
 - Isomers
 - Ionization energy
 - Experimental cross sections
 - Fission barriers
 - Branch ratios
 -

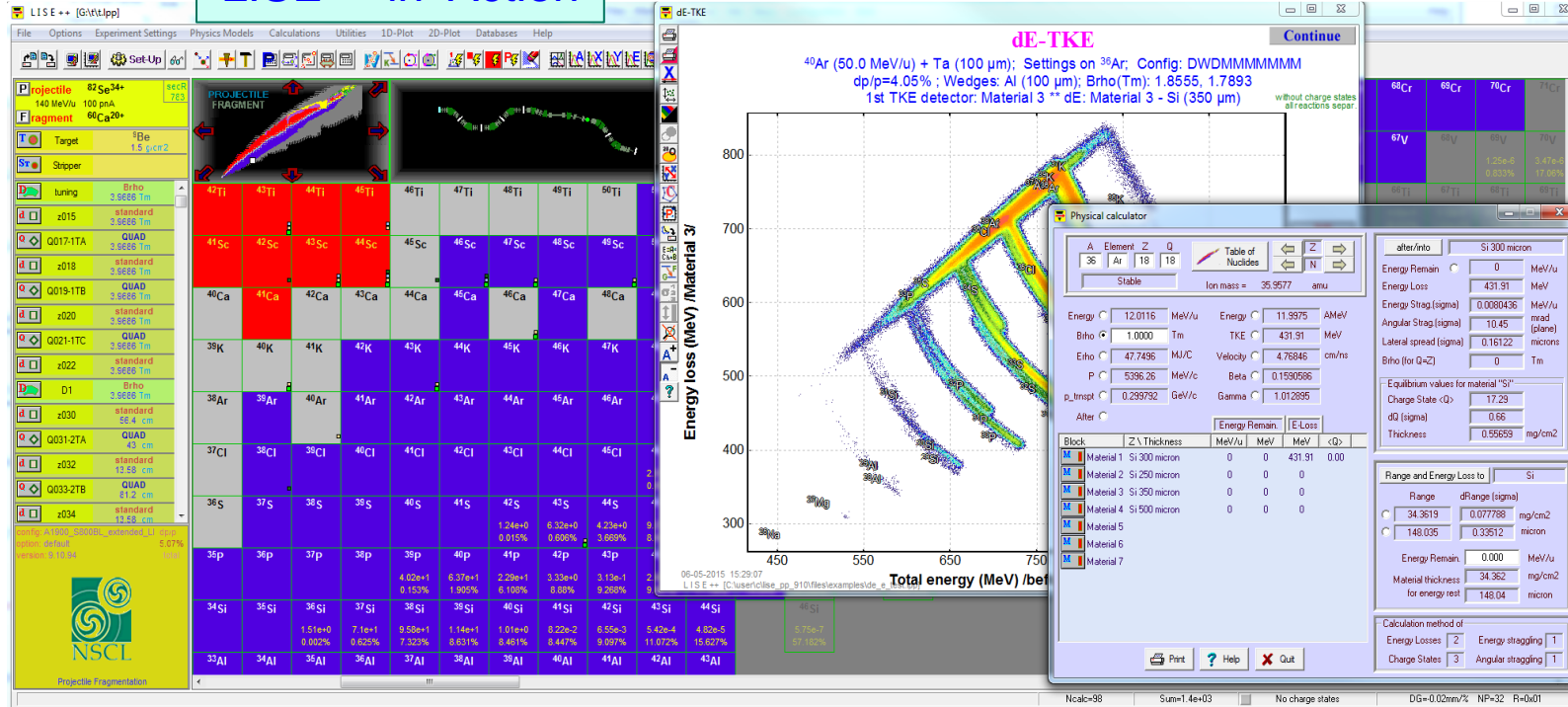
- ❖ Needs in detailed information
 - Excitation energy of (fissile) nuclei after abrasion
 - Limiting temperature

□ The LISE++ program is designed

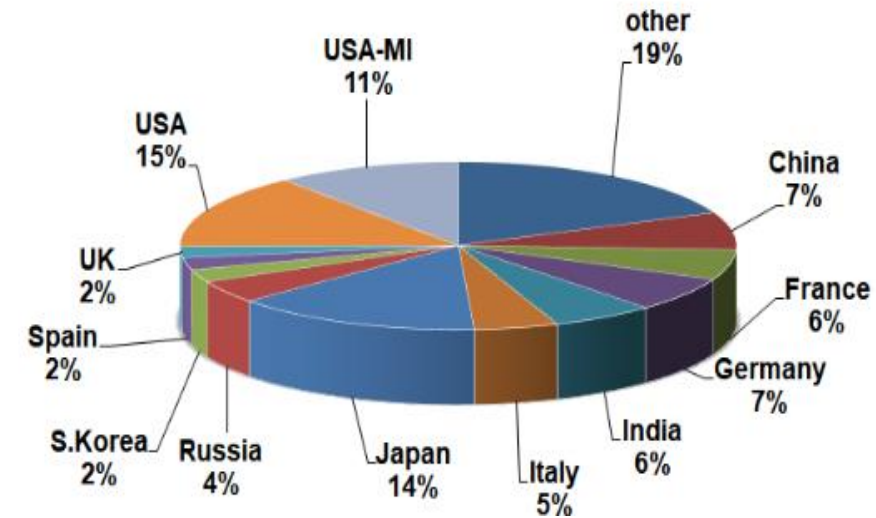
- to predict intensities and purities of rare isotope beams for the planning of future experiments with in-flight separators,
- is also essential for tuning of rare isotope beams where results can be quickly compared to on-line data.

□ The LISE++ program is widely used

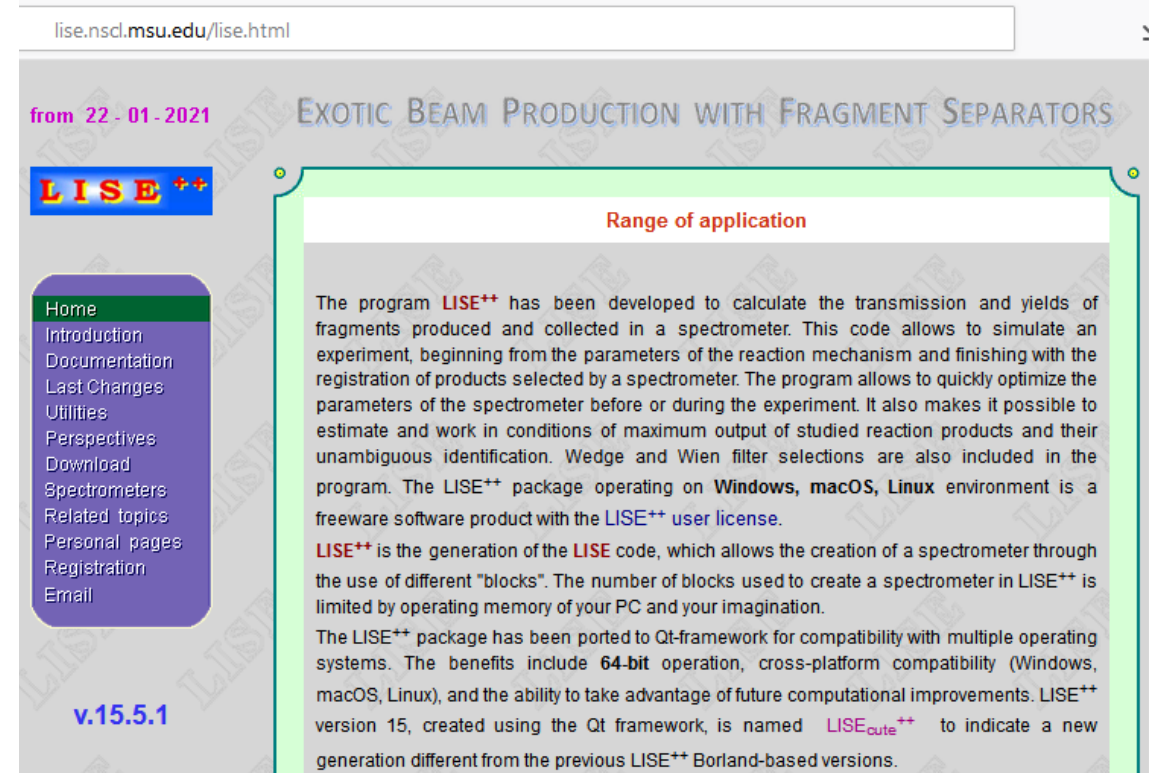
LISE++ in Action



The LISE++ code geography



- ❑ The LISE++ package (including codes PACE4, Global, Charge, MOTER, ETACHA4, GEMINI++, Spectroscopic Calculator) operating on **Windows, macOS, Linux** environment
- ❑ The LISE++ package is maintained by **LISE++ group @ Michigan State University** and is freely available and distributable through the LISE++ website: <<http://lise.nscl.msu.edu>>



- Spectrometer design with different sections called "blocks"
(magnetic and electric multipoles, solenoid, velocity filter, RF deflector and buncher, material in beam, drift, and others)
- a user-friendly interface that helps to construct a fragment separator from the different blocks.

Block	Given Name	Z-q	Length, m	Enable
Target	Target			<input checked="" type="checkbox"/>
Stripper	Stripper			<input checked="" type="checkbox"/>
** Dipole	D1	0	8.719	<input checked="" type="checkbox"/>
slits	I1_slits		0	<input checked="" type="checkbox"/>
Wedge	I1_wedge			<input type="checkbox"/>
** Dipole	D2	0	8.767	<input checked="" type="checkbox"/>
Material	I2_PPAC0			<input type="checkbox"/>
slits	I2_slits		0	<input checked="" type="checkbox"/>
Wedge	I2_wedge			<input checked="" type="checkbox"/>
Material	I2_PPAC1			<input type="checkbox"/>
Material	I2_SCI			<input type="checkbox"/>
** Dipole	D3	0	8.767	<input checked="" type="checkbox"/>
slits	I3_slits		0	<input type="checkbox"/>
Wedge	I3_wedge			<input type="checkbox"/>
** Dipole	D4	0	9.39	<input checked="" type="checkbox"/>
Material	FP_PPAC0			<input checked="" type="checkbox"/>
Material	FP_PPAC1			<input checked="" type="checkbox"/>
slits	FP_slits		0	<input checked="" type="checkbox"/>
Material	XF_SCI			<input type="checkbox"/>
Material	FP_PIN			<input checked="" type="checkbox"/>

Selected block	
Enable <input checked="" type="checkbox"/>	Dispersive (M-dipole)
Set block name automatically <input type="checkbox"/>	Block Length [m] 8.719
Block name = D1	Length after this block [m] 8.719
Charge State (Z-Q) = 0	Sequence number 3

Total	
Number of Blocks	26
Length [m]	35.643

- Analytical and Monte Carlo calculation of fragment transmission
- Ion optical calculation up to 2nd order (5th order use in MC mode)
- Minimization of Ion optic properties

Production Mechanism

$^{48}\text{Ca} (140.0 \text{ MeV/u}) + \text{Be} \rightarrow ^{42}\text{S}$

Reactions | Energy Loss, Straggling | Charge states | Databases: Masses, Isomers

Reactions

Projectile Fragmentation ☑ additionally calculate yields for the next reactions
 Fusion → Residual
 Fusion → Fission
 Coulomb fission
 Abrasion-Fission
 Two Body Reactions
 ISOL mode

Projectile fragmentation

$A_1 > A_2 \geq A_3$

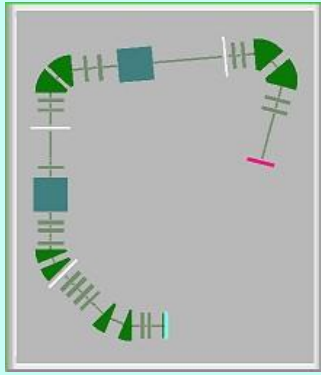
Make default

OK Cancel Help

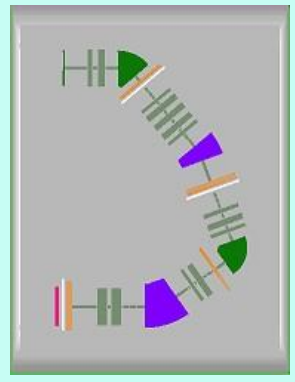
- Not only using classical reaction mechanism models, but actively developing fast and accurate in-house models
- Includes fragment production in materials (wedges, detectors)

			cit-ns
O.B.Tarasov	Analysis of momentum distributions of projectile fragmentation products	NPA 734 (2004) 536-540	35
O.B.Tarasov, D.Bazin	Development of the program LISE: application to fusion–evaporation	NIM B204 (2003) 174-178	92
O.B.Tarasov, A.C.C.Villari	Fusion–fission is a new reaction mechanism to produce exotic radioactive beams	NIM B 266 (2008) 4670-4673	5
O.B.Tarasov	LISE ⁺⁺ development: application to low-energy fission of projectiles at relativistic energies	ENAM2004: EPJ A25 (2005) 751	3
O.B.Tarasov	LISE ⁺⁺ development: Abrasion-Fission	Preprint NSCL MSU, MSUCL-1300, 09.2005	

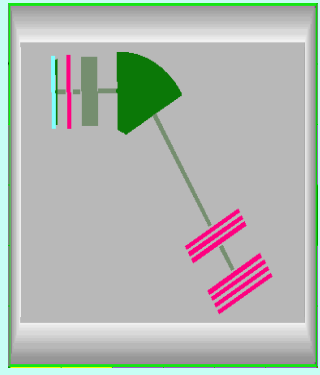
Application Examples



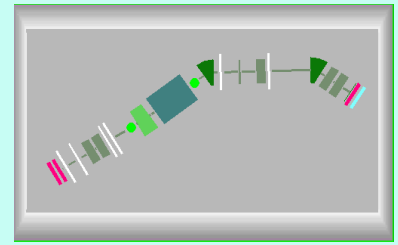
SECAR, MSU



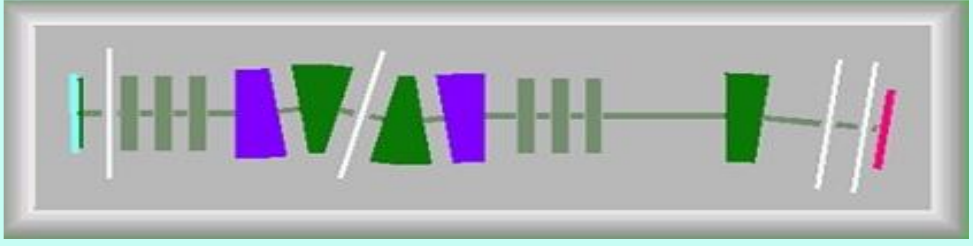
DRAGON, Canada



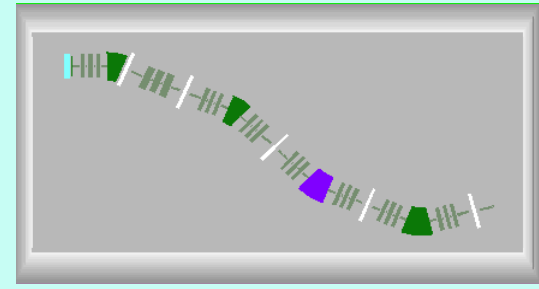
PRISMA, Italy



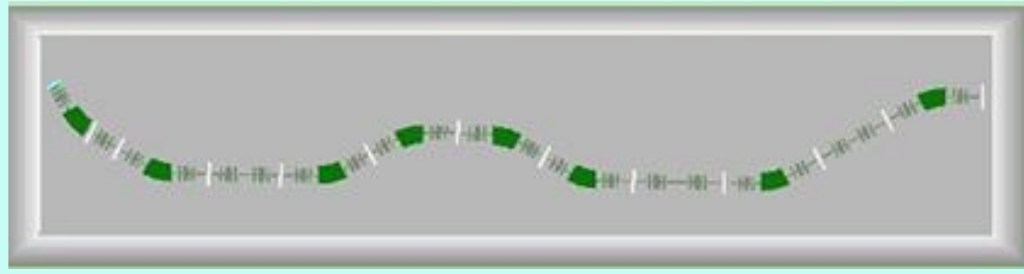
MARS, TAMU, USA



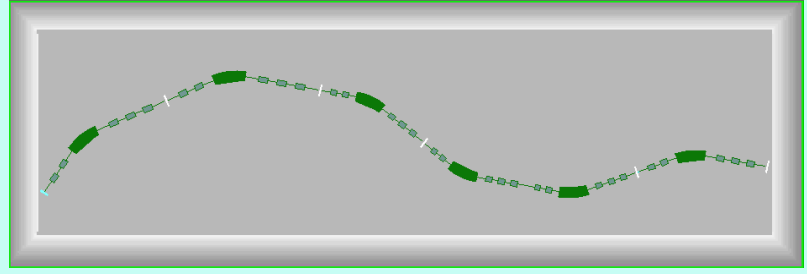
SHELS, Russia



S³, France



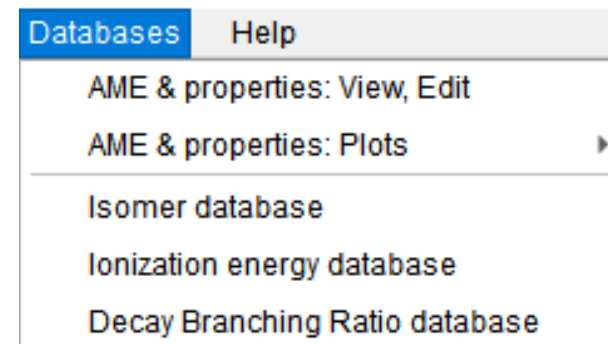
BigRIPS+ZeroDegree, Japan





SuperFRS_HEB, Germany

The LISE++ code may be applied at low, medium, and high-energy facilities (fragment- and recoil-separators with electrostatic and/or magnetic selections)

- Atomic Masses 
- Ionic Masses 
- Isomeric states database 
- Fission barrier database 
- Experimental production cross sections 
- Decay branching ratio database 
- Compound material database 
- Discovery database 



- *Intrinsic datasets (ranges, model parameterization, and so on)*
- Set of separator configurations /LISE/ 
- NSCL & FRIB secondary beam rates /LISE/ 

- Ion mass for **optics settings**, isotope selection
- **Production rates** with built-in reaction models (**separation energies** for de-excitation cascade calculations in abrasion-ablation, fusion-residues, all fission reactions)
- Half-life calculation, decay analysis
- Plotting isotope properties (energy separation, binding energies, $T_{1/2}$)

Production Mechanism

$^{48}\text{Ca} (140.0 \text{ MeV/u}) + \text{Be} \rightarrow ^{42}\text{S}$

Reactions | Energy Loss, Straggling | Charge states | Databases: Masses, Isomers

Masses

Database + Calculations DataBase: 0 - AME2016 (database)
 only Calculations Formula: 2 - LDM#1 + shell corrections (O.T.)

User's MassExcess File: AME2016.lme [Browse]

Ion mass

Take into account electron binding energies for ion mass calculations (Recommended)

Isomer database: isomer.dbf [Browse]

USER database: user_database.dbf [Browse]

Make default [OK] [Cancel] [Help]

Databases

DataBase: 0 - AME2016 (database)

Index=16026 Sulfur N=26

A: 42 Element: S Z: 16 Table of Nuclides
 Beta-decay Z N

$T_{1/2}$: 1.016 sec
 $\delta T_{1/2}$: 0.015

	Value	Error	
Mass Excess	-17.6377		MeV
Binding Energy	344.1155	0.0028	MeV
β decay	7.1941	0.0597	MeV
β^+ decay	-18.6474	0.3144	MeV
S_{2n}	10.9425	0.0049	MeV
S_{2p}	37.6454	0.3451	MeV
Q_{α}	-15.8924	0.1048	MeV
S_{1n}	6.7005	0.0050	MeV
S_{1p}	19.9470	0.1202	MeV

Put "*" into a cell if value is unknown

272

Half-life (sec)
 Experimental Database: 1.02e+00
 Calculation: β -decay: * 1e-4* α -decay: p-emission:

LISE++ built-in mass excess files

AME2003.lme
 AME2011.lme
 AME2016.lme
 FRDM2012.lme
 hfb17.lme
 hfb22.lme
 hfb27.lme
 hfb8.lme
 hfb9.lme
 ktuy.lme
 Moller95.lme
 tuy.lme
 WS4.lme
 WS4_RBF.lme
 FRIB_mass\SKMS.lme
 FRIB_mass\SKP.lme
 FRIB_mass\SLY4.lme
 FRIB_mass\SV-MIN.lme
 FRIB_mass\UNEDF0.lme
 FRIB_mass\UNEDF1.lme
 RMF_mass\ddme2.lme
 RMF_mass\ddmed.lme
 RMF_mass\ddpc1.lme
 RMF_mass\nl3s.lme

We need more experimental data

☐ Ion mass for E-M device precise settings and isotope selection

☐ Generation of X-ray spectra (in future with ETACHA4)

using

- AME2012 (or other Mass model)
- Ionization Energy Database (NIST Atomic Spectra Database Ionization Energies)

Example: $^{238}\text{U}^{92+}$ ion mass

- v.9.8.114 atomic mass was used 238.0508 amu
- v.9.8.117 correction for e- masses 238.0003 amu
- v.9.10.131 correction for e- binding energies 238.0011 amu

Ion Mass Calculator / Ionization Energy Database

A	Element	Z	Table of Nuclides		
238	u	92	← Z →	← N →	← →
Stable					

Atom & Ion Masses				
Charge state	Ground shell configuration	Total binding energy (keV)	Mass amu	Mass GeV
Q=0 atom	[Rn].5f3.6d.7s2	761.513	238.05079	221.742894
Q= 92		0	238.00114	221.696644
Q=Z full stripped		0	238.00114	221.696644

Comments

Ionization energies are taken from the NIST Atomic Spectra Database <http://www.nist.gov/pml/data/asd.cfm> with in-house extrapolation for heavy ions. Their configurations are marked by the symbol "?".

The database range is $1 \leq Z \leq 110$.

For heavier ions no electron binding corrections. Binding energies are determine by summing up all relevant ionization energies.
 $Mi(A,Z,Q) = Ma(A,Z) - Q * Me + TBE(0) - TBE(Q)$

IsoSeq -- Isoelectronic sequence
 Ground Shells -- Ground-state electronic shells
 Ioniz.Energy -- Ionization energy [keV]
 Total BE -- Total binding energy [keV]

Designations used in the ground shell lists:

[Ne] = 1s2.2s2.2p6
 [Ar] = [Ne].3s2.3p6
 [Kr] = [Ar].3d10.4s2.4p6
 [Cd] = [Kr].4d10.5s2
 [Xe] = [Cd].5p6
 [Hg] = [Xe].4f14.5d10.6s2
 [Rn] = [Hg].6p6

? Link
✓ Exit

"U" ----- Z = 92 ----- Uranium						
Shell	Z	Q	Isoel Seq	Ground Shells	Ioniz. Energy	Total BE
7	92	0+	U	[Rn].5f3.6d.7s2	0.0062	761.513
7	92	1+	Pa	[Rn].5f3.7s2	0.0116	761.507
5	92	2+	Th	[Rn].5f4	0.0198	761.495
5	92	3+	Ac	[Rn].5f3	0.0367	761.476
5	92	4+	Ra	[Rn].5f2	0.046	761.439
5	92	5+	Fr	[Rn].5f1	0.06	761.393
6	92	6+	Rn	[Hg].6p6	0.089	761.333
6	92	7+	At	[Hg].6p5	0.101	761.244
6	92	8+	Po	[Hg].6p4	0.116	761.143
6	92	9+	Bi	[Hg].6p3	0.129	761.027
6	92	10+	Pb	[Hg].6p2	0.158	760.898
6	92	11+	Tl	[Hg].6p	0.173	760.740
6	92	12+	Hg	[Xe]....	0.21	760.567
6	92	13+	Au	[Xe]....	0.227	760.357
5	92	14+	Pt	[Xe].4f14.5d10	0.323	760.130
5	92	15+	Ir	[Xe].4f14.5d9	0.348	759.807
5	92	16+	Os	[Xe].4f14.5d8	0.375	759.459
5	92	17+	Re	[Xe].4f14.5d7	0.402	759.084
5	92	18+	W	[Xe].4f14.5d6	0.431	758.682
5	92	19+	Ta	[Xe].4f14.5d5	0.458	758.251
5	92	20+	Hf	[Xe].4f14.5d4	0.497	757.793
5	92	21+	Lu	[Xe].4f14.5d3	0.525	757.296
5	92	22+	Yb	[Xe].4f14.5d2	0.557	756.771
5	92	23+	Tm	[Xe].4f14.5d	0.585	756.214
4	92	24+	Er	[Xe].4f14	0.73	755.629
5	92	25+	Ho	[Cd].4f14.5p5	0.77	754.899

Cross section file

Cross section file: 86Kr_AI_70AMeV.cs

Operations with User (memory) CS

- 2D-Plot of User (memory) CS
- Copy AA (LisFus,Fiss) CS to memory
- Remove all CS from memory

Number of User CS for this reaction = 62
Total number of User CS = 62

Method to keep User CS

- Attached CS file
- Inside LISE ++ file

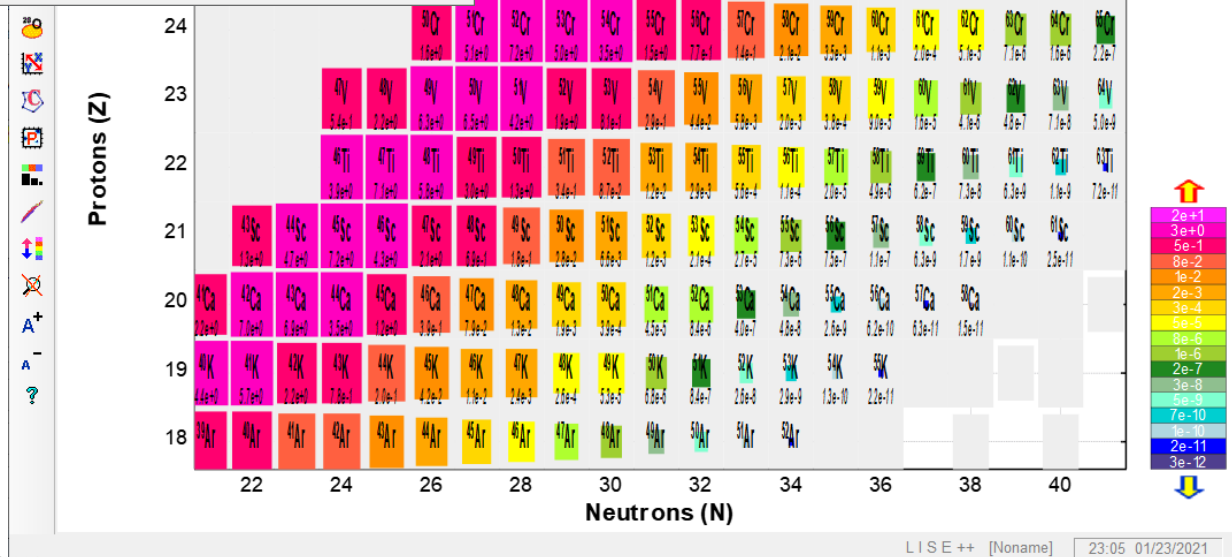
Cross section file format

The CS file is in ASCII format. Comment strings begin with " ! ".

There are five columns: "Z", "N", "CS value", "CS error", "R#" where Z is atomic number, N is number of neutrons. CS value error is equal to 0 if fourth column is absent. Columns can be separated by space, tabulation sign, or comma. R# - reaction order number

where CS - cross sections; "User" is identical to "memory CS"; Calculated CS: AA ("Abrasion-Ablation"), Fusion-Evap. ("LisFus"), Coulomb Fission, Abrasion-Fission.

Buttons: OK, Cancel, Help



LISE++ built-in cross section files

- \129Xe_AI_790AMeV.cs
- \136Xe_AI_760AMeV.cs
- \208Pb\208Pb_1H_1AGeV_evap.cs
- \208Pb\208Pb_1H_1AGeV_fission.cs
- \208Pb\208Pb_2H_1AGeV_evap.cs
- \208Pb\208Pb_2H_1AGeV_fission.cs
- \238U\238U_Be_750AMeV_fission.cs
- \238U\238U_d_1AGeV_fission.cs
- \238U\238U_d_1AGeV_fragmentation.cs
- \238U\238U_p_1AGeV_fission.cs
- \238U\238U_p_1AGeV_spallation.cs
- \238U\238U_Pb_1AGeV_fission.cs
- \238U\238U_Pb_1AGeV_fragmentation.cs
- \40Ar_Be_1AGeV.cs
- \40Ar_C_240AMeV.cs
- \48Ca-Ta_90AMeV.cs
- \58Ni_Be_650AMeV.cs
- \78Kr_Ni_75AMeV.cs
- \82Se_Be_140AMeV.cs
- \82Se_W_140AMeV.cs
- \86Kr_AI_70AMeV.cs

+ user can enter his own data

- Need more! (installer size?)
- External link?
- Data format
- Reactions with exotic nuclei

	Common Name	Atomic Stoich.	Density	
Nuclear physics materials	Aluminum Oxide alpha	Al ₂ O ₃	3.98	Input
Plastic-polimers	Bakelite	H ₉ C ₉ O ₁	1.45	Input
Liquids	1-2 - Ethanediol	H ₆ C ₂ O ₂	1.1088	Input
Gases	Acetylene	H ₂ C ₂	0.0010825	Input
	Air (gas mixture **)	O ₂₁ N ₇₈ Ar ₁	0.001205	
	Allene Propadiene	H ₄ C ₃	0.0016656	
	Ammonia	H ₃ N ₁	0.00070804	
	Butane	H ₁₀ C ₄	0.0024164	
	1-3-Butadiene	H ₆ C ₄	0.0022488	
	Carbon Dioxide	C ₁ O ₂	0.0018296	
	Carbon Tetrafluoride	C ₁ F ₄	0.0036586	
	Cyclobutane	H ₈ C ₄	0.0023326	
	Cyclopropane	H ₆ C ₃	0.0017495	
	Cyclopropene	H ₄ C ₃	0.0016656	
	1-2 Difluorethane	H ₄ C ₂ F ₂	0.0027459	
	1-2 Difluorethene	H ₂ C ₂ F ₂	0.0026621	
	Ethane	H ₆ C ₂	0.0012501	
	Ethane - Hexafluoride	C ₂ F ₆	0.0057376	
	Ether Dimethyl	H ₆ C ₂ O ₁	0.0019153	
	Ethylene	H ₄ C ₂	0.0011663	
	Ethylene Sulfide	H ₄ C ₂ S ₁	0.0024994	
	Hydrogen Sulfide	H ₂ S ₁	0.0014169	
	Methane	H ₄ C ₁	0.00066697	
	Methane Chloro-Tri.Freongas	C ₁ F ₃ CL ₁	0.0043427	
	Methane Dichloro-Di. Freon-12	C ₁ F ₂ CL ₂	0.0050268	
	Methane Dichloro-Fl. Freon-21	H ₁ C ₁ F ₁ CL ₂	0.0042789	
	Nitric Oxide	N ₁ O ₁	0.0012475	
	Nitrous Oxide	N ₂ O ₁	0.0018298	
	P10 (10% Methane in Argon) **	C ₂ H ₈ Ar ₉₀	0.00159	
	Propane	H ₈ C ₃	0.0018333	
	Propylene Sulfide	H ₆ C ₃ S ₁	0.0030826	
	Sulfur Hexafluoride	F ₆ S ₁	0.006072	
	Water vapor	H ₂ O ₁	0.00074895	

Gas density

Molecular formula
 Gas mixture

Parameter	Value	Dimension
Temperature (K)	<input type="text" value="293.15"/>	K
Pressure (Torr)	<input type="text" value="760"/> <input type="text" value="760"/>	Torr
Density	<input type="text" value="2.4164"/> <input type="text" value="2.4164"/>	mg/cm ³ kg/m ³ g/L

Fission Barrier

A Element Z

254 Rf 104

Spontaneous fission

Cohen barrier information

Barrier vanishes at = 64 hbar

Fission Barrier Plot : f(A,Z,N)

For models # 0,1,2

Barfac = 8 factor to multiply the fission barrier (default value 1)

Use LISE shell corrections for LDM

Use odd-even corrections for LDM

Odd-even Delta parameters

for Protons 9 9.0 MeV

for Neutrons 2.5 2.5 MeV

Use in the code

0 - "Barfit" -> invalid for this isotope(A,Z)

1 - "FisRot" - S.Cohen et al.,An.P 82(1974)

2 - LDM - W.Myers_W.Swiatecki,NP81(1966)

3 - FILE: A.Mamdouh et al,NPA679(2001)337

4 - FILE: Experimental barriers

5 - FILE: P.Moller et al.,LANL-UR-08-4190

6 - FILE: P.Moller et al., PRC91(2015)024310

Fission Barrier at L=0

Barrier at L_x 10

G.S. Energy at L_x (MeV)

4.81		
6.53	6.28	0.32
7.18		
5.3		
-		
5.87		
5.87		

for models # 3, 4

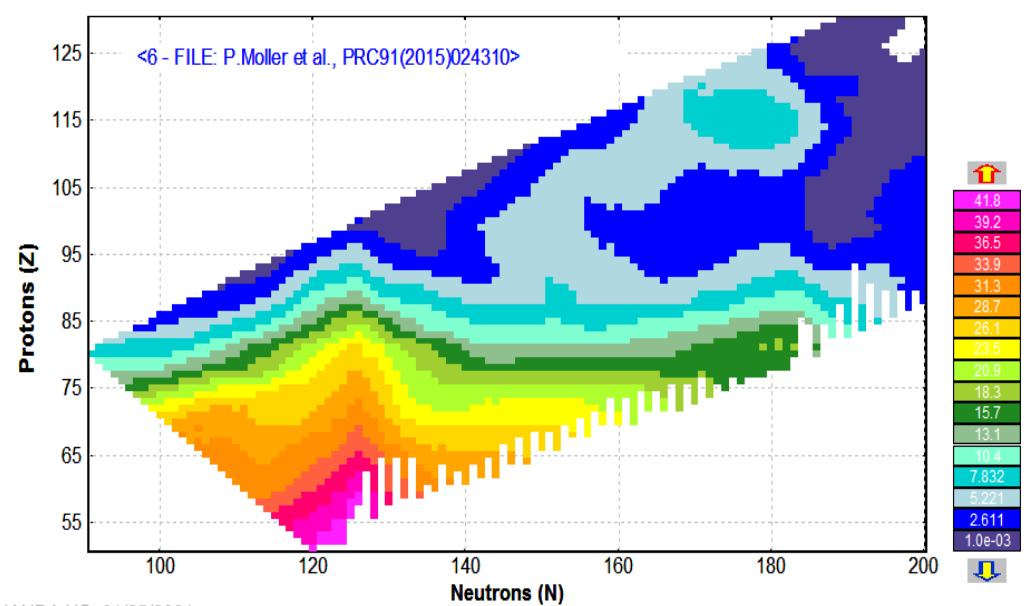
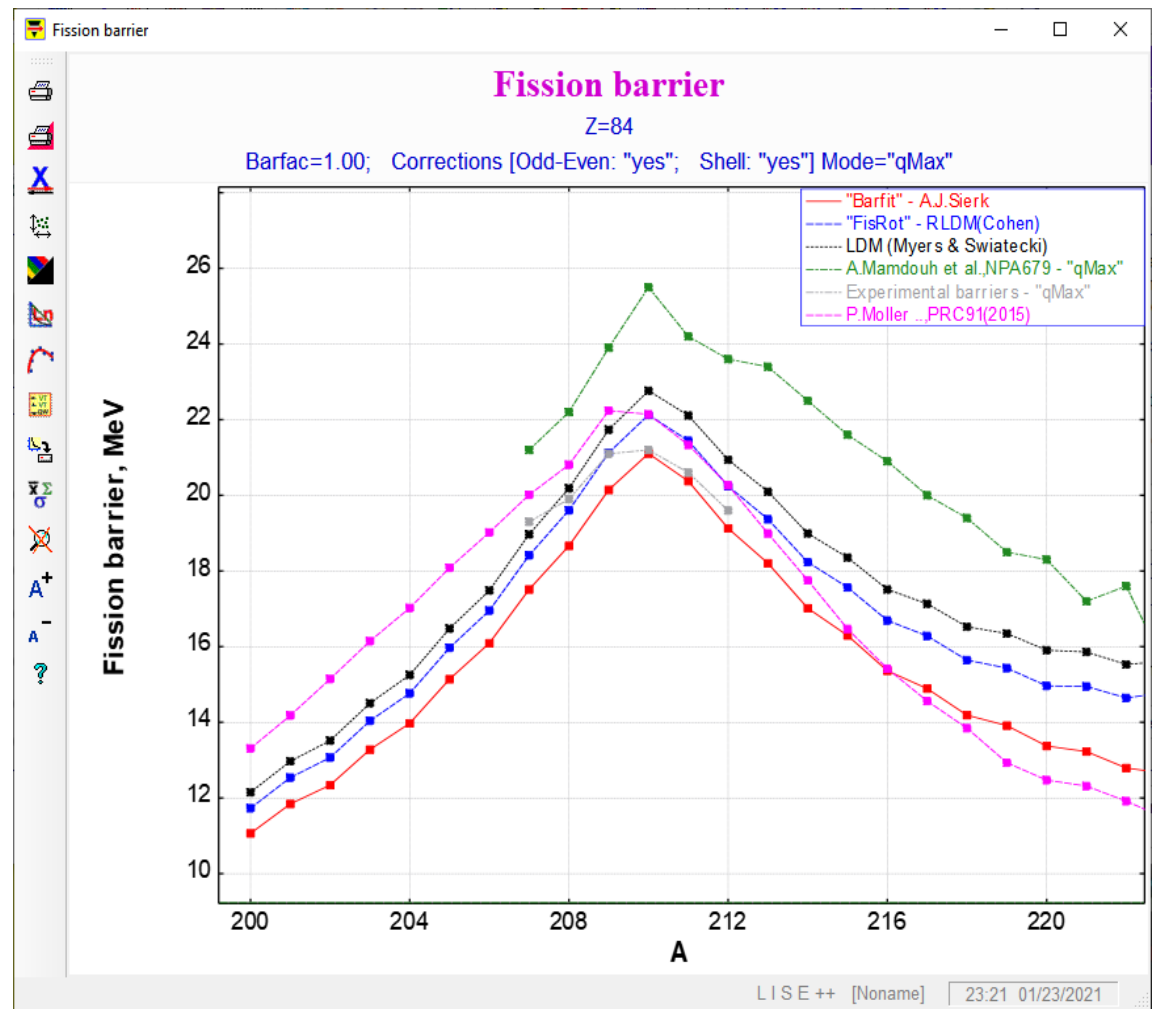
in out max (in,out)

For models # 3,4

if FILE data are absent then use LDM model #

1 - "FisRot" - S.Cohen et al.,An.P 82

Make default

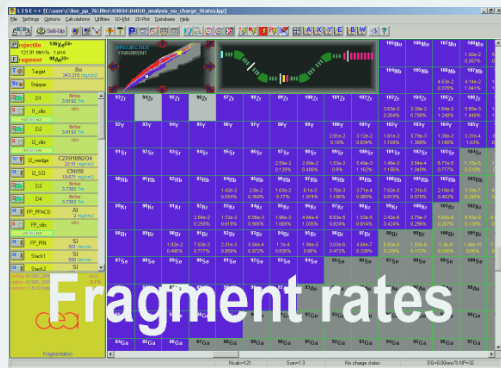
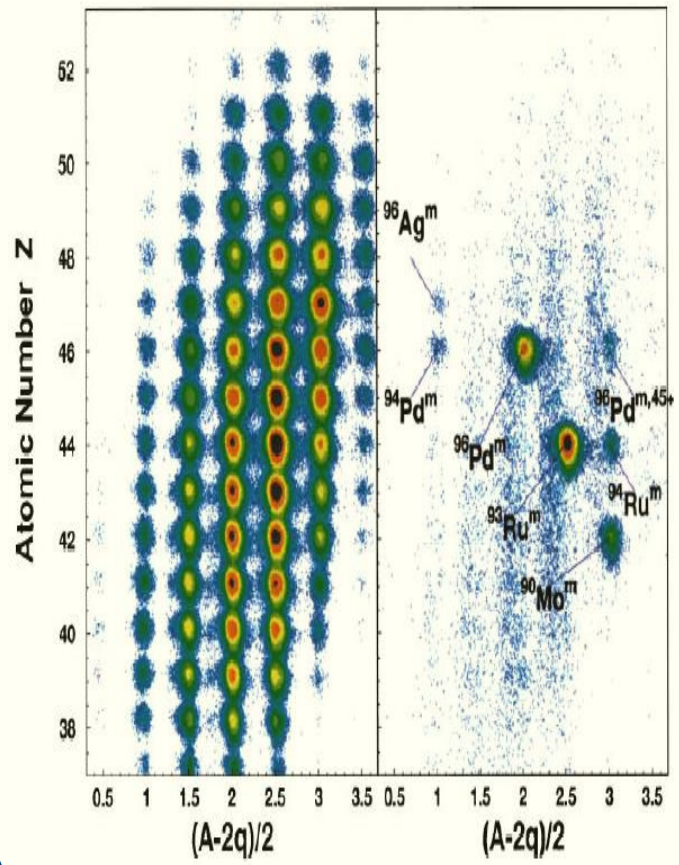


Experiment

PHYSICAL REVIEW C VOLUME 55, NUMBER 3 MARCH 1997

New μ s isomers in $T_z=1$ nuclei produced in the $^{112}\text{Sn}(63.4\text{ MeV})+^{100}\text{Ni}$ reaction

R. Grzywacz,^{1,2} R. Anne,² G. Auger,² C. Borcea,² J. M. Corre,² T. Dörfler,⁴ A. Fomichev,⁵ S. Greife,⁶ H. Grawe,⁷ D. Guillemaud-Mueller,⁸ M. Huyse,⁹ Z. Janas,⁷ H. Keller,⁷ M. Lewitowicz,⁷ S. Lukyanov,^{5,2} A. C. Mueller,⁶ N. Orr,⁹ A. Ostrowski,² Yu. Penionzhkevich,⁵ A. Piechaczek,⁸ F. Pougheon,⁶ K. Rykaczewski,¹⁰ M.G. Saint-Laurent,² W. D. Schmidt-Ott,⁸ O. Sorlin,⁶ J. Szerypo,¹ O. Tamsos,¹² J. Wauters,⁸ J. Zylicz¹

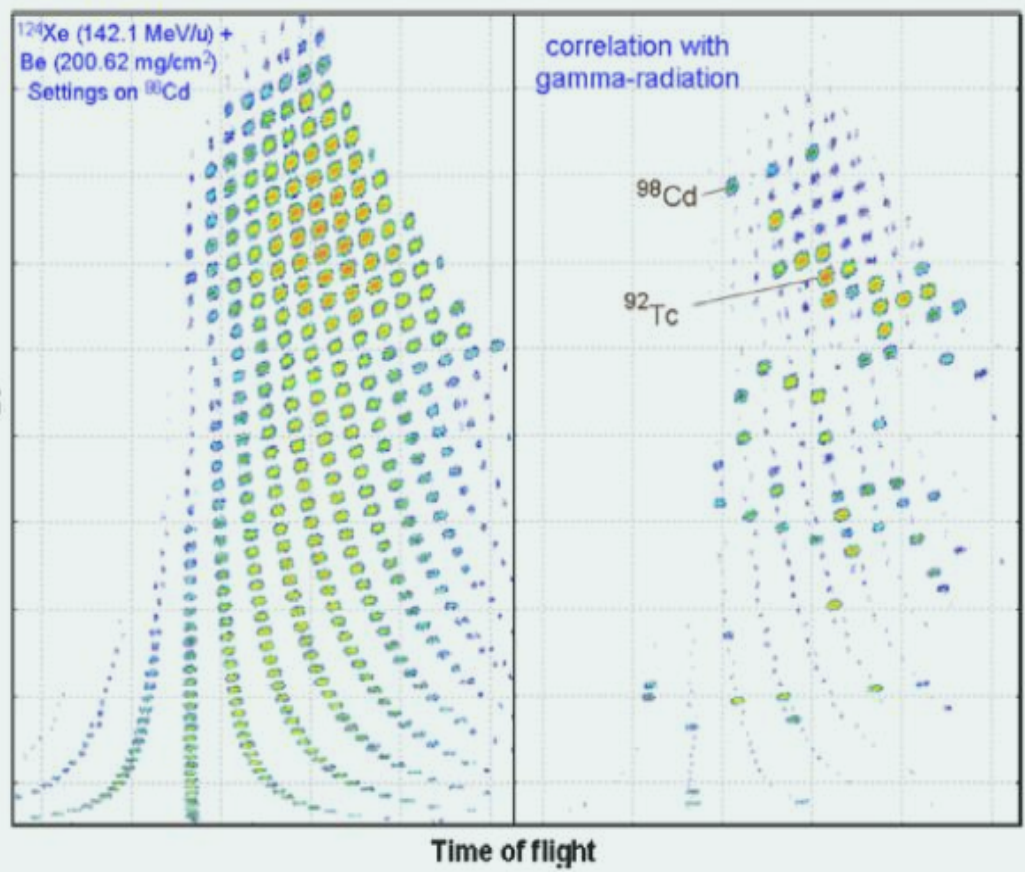


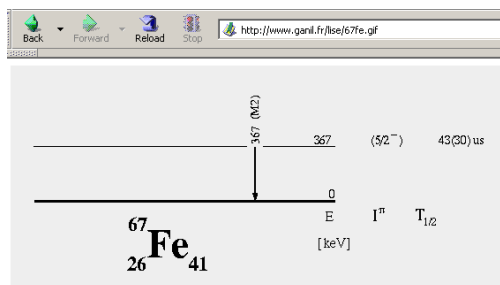
Fragment rates

LISE++
 γ -database

γ -registration
settings

LISE++ simulations





Old GANIL database available through LISE

Nuclear Levels and Gammas Search

Specify Nuclei : Nucleus: Ex: 232Th or th232 or 232-Th or th-232 or Z / Element: A: N:

$20 \leq Z \leq 54$ $\leq A \leq$ $\leq N \leq$

E(level) condition: enabled disabled $100 \leq E_{level}(keV) \leq 20000$

Decay Mode condition: enabled disabled Decay Mode: ANY

Jn(level) condition: enabled disabled J = Order: ALL Parity: ANY

$T_{1/2}(level)$ condition: enabled disabled $1 \leq ns \leq T_{1/2} \leq 100$ us

γ condition #1: enabled disabled $100 \leq E_{\gamma}(keV) \leq 3000$ Multipolarity: ANY

γ condition #2: enabled disabled $0 \leq E_{\gamma}(keV) \leq 40000$ Multipolarity: ANY

Internet database (NNDC) region of stable isotopes

Experiment#	Isomers	Ex. Energy (keV)	γ -energies (keV)	Half-life (μ s)
03034n	59Cr	503n	193n	96n
64Mn	135n	7n	>100n	
65Fe	364n	7n	0.430n	
67Fe	367n	7n	64n	
66Co	173n	7n	1.21n	
66Co	64n	7n	>100n	
69Ni	2701n	148n	0.439n	
70Ni	2600n	183n	0.232n	
72Cu	270n	7n	1.76n	
72Cu	2673n	7n	0.319n	
80Se	273n	111, 159n	5.46n	
92Zn	254n	254 and 266 from two levels	57n	
97S	308n	141, 167n	0.170n	
97S	830n	52n	0.255n	
98Y	171n	90, 171n	0.62n	
98Y	496n	50, 121, 170, 204n	7.6n	
98Y	1181n	111, 119, 130, 159, 186, 476, 596n	0.83n	
99Y	2141n	88, 106, 159, 198, 223, 245, 269, 273, 283, 346, 882, 1166, 1433, 1520n	8.6n	
107Mo	66n	66n	0.470n	
117Ru	7n	184n	>.5n	
121Pd	7n	136n	0.694n	
123Ag	7n	349, 384, 391, 630, 386, 714, 733, 769, 1049, 1077, 1133n	0.214n	
124Ag	7n	156, 1132n	1.9n	
125Ag	7n	670, 684, 715, 729n	0.310n	
125Cd	7n	409, 720, 743, 786, 868, 922n	>.5n	
126Cd	7n	220, 248, 402, 405, 652, 807, 813, 836n	0.270n	
127Cd	7n	739, 771, 821, 909n	1.9n	
129In	7n	334, 339n	2.9n	
66Zn	117Ru	7n	184n	>.5n
121Pd	7n	136n	0.694n	
123Ag	7n	349, 384, 391, 630, 386, 714, 733, 769, 1049, 1077, 1133n	0.214n	
124Ag	7n	156, 1132n	1.9n	
125Ag	7n	670, 684, 715, 729n	0.310n	
126Cd	7n	220, 248, 402, 405, 652, 807, 813, 836n	0.270n	
127Cd	7n	739, 771, 821, 909n	1.9n	
129In	7n	334, 339n	2.9n	

Private communications

LISE++ database (dbf-format)

New experimental data

Isomer Database

Database Index: 43190738

for this isotope: Current isomeric γ -ray: 1, Total number of isomer γ -rays: 1

	Value	Error	
γ - energy	738.1	0.2	keV
Isomeric ratio (level population)	10	AP	%
$T_{1/2}$	2.0E-1	5.00E-3	μ s
Level energy	738.1	0.1	keV
J^{π}	7/2-		
I_{γ}	100.	AP	%
M_{γ}	M2+E3		
M ratio	-0.13	-0.02	
Conversion Coef.			
Data source	NNDC		
User Name	OT		

Buttons: Save, Quit, Help, Add Record, Delete Record, Show Structure

• Need more experimental data! (updated with recent RIKEN data)

P_n for $2 \leq Z \leq 28$ are taken from

Nuclear Data Sheets 128 (2015) 131-184

Evaluation of Beta-Delayed Neutron Emission Probabilities and Half-Lives for $Z = 2 - 28$

M. Birch,¹ B. Singh,^{1,*} I. Dillmann,² D. Abriola,³ T.D. Johnson,⁴ E.A. McCutchan,⁴ and A.A. Sonzogni⁴

¹Department of Physics and Astronomy, McMaster University, Hamilton, Ontario L8S 4M1, Canada

²TRIUMF, Vancouver, British Columbia V6T 2A3, Canada

³Department of Physics, TANDAR Laboratory, C.N.E.A., Buenos Aires, Argentina

⁴National Nuclear Data Center, Brookhaven National Laboratory, Upton, NY 11973-5000, USA

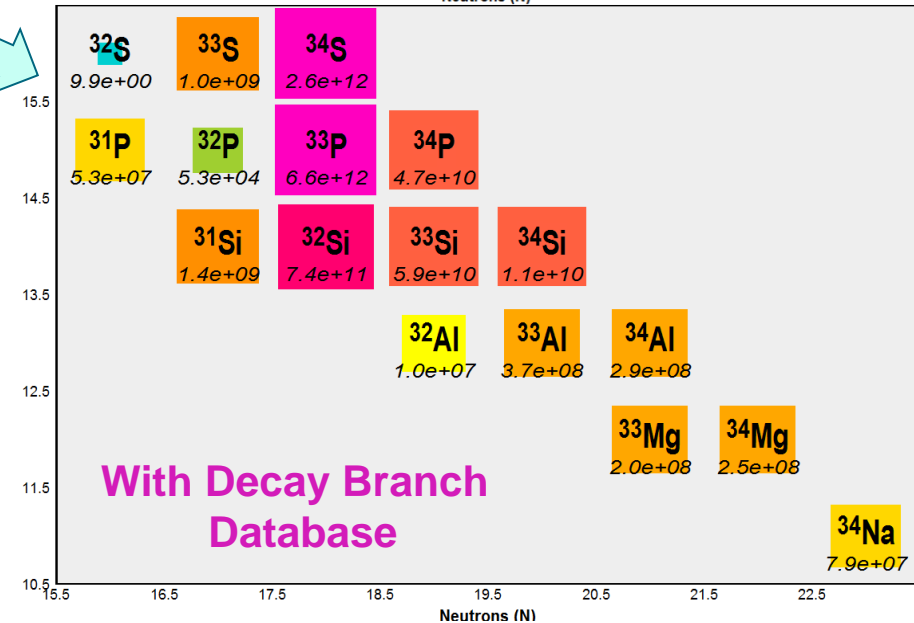
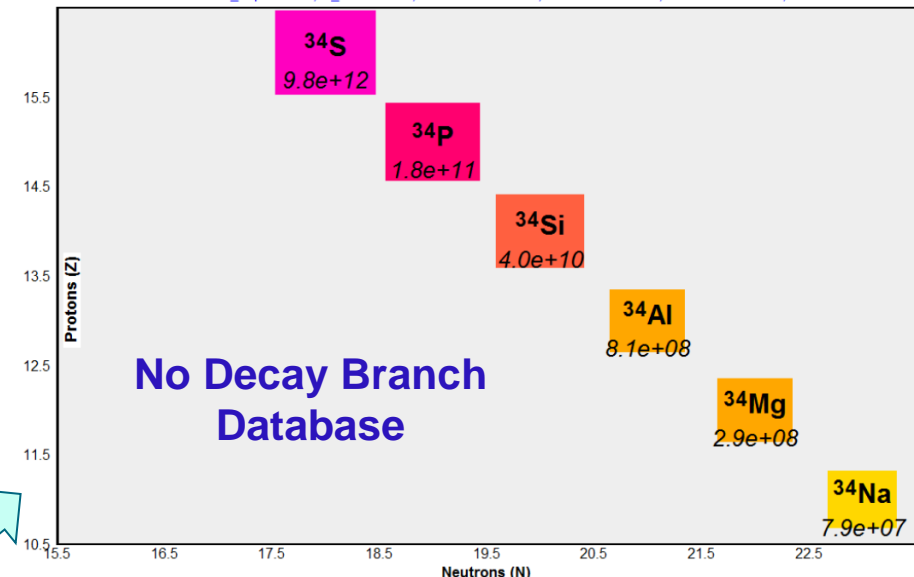
We present an evaluation and compilation of β -delayed neutron probabilities and half-lives for nuclei in the region $Z = 2 - 28$ ($^4\text{He} - ^{86}\text{Ni}$). This article includes the recommended values of these quantities as well as a compiled list of experimental measurements for each nucleus in the region for which β -delayed neutron emission is possible. The literature cut-off for this work is August 15th, 2015. Some notable cases as well as new standards for β -delayed neutron measurements in this mass region are also discussed.

Other branching ratios and P_n for $38 \leq Z$ are taken from NNDC

Ratios for higher Z will be entered soon.

Radioactive decay residues

Initial isotope: ^{34}Na
 Irradiation Time (IT) = 1.00e+03 sec; Decay Time (DT) = 1.00e-06 sec; Irr.Rate = 1.00e+10 pps; Plot All isotopes
 N_Implant=100, N_Resid=1000, Abs.Error=1.0e-11, Rel.Error=1.0e-03, Threshold=1.0e-10, Model="ODE"



Decay branching ratio

Sodium

A	Element	Z
34	Na	11

Beta- and Beta-n decay

Branching

Beta - 85 %

Beta - n 15 %

Generate Z-wallet

Quit

Radiation residue calculator

Mode to implant

1. One nucleus to implant. Chose manually here

Yield = Number of atoms; N of DI = Number of Different Isotopes; Final Time (FT) = Irradiation Time (IT) + Decay Time (DT)

2. List of isotopes to implant from file

3. Select detector to obtain the list of isotopes stopped in

1. Chose fragment to implant

A	Element	Z
34	na	11

Beta-decay

$T_{1/2} = 5.50e-03$ sec

Implantation Rate = 1e+10 pps

Yield of this nucleus @ Irradiation time (IT) = 7.88e+7

Yield of this nucleus @ Final time (FT) = 7.88e+7

Irradiation (Implantation)

IT : Irradiation Time [sec] = 1000

N of DI @ time (IT) = 6

Radiation Residues as Function of time (DT)

DT : Decay Time after irradiation (sec) = 0

N of DI @ time (FT) = 6

Total Yield @ time (FT) = 1e+13

Calculate

Options

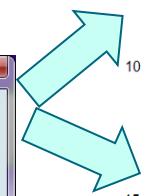
1D : Residues as function of time

1D : Activity as function of time

2D : Final Residues (@ TF)

CAUTION RADIATION AREA

Elapsed time is 00:00:00.71 or 0.71 sec



Database information: ^{129}Sm

[Save As](#)
[Print](#)
[LISE database](#)
[Decay analysis](#)
[Branching ratio](#)
[Z-wallet NNDC](#)
[A, Z NNDC](#)
[A, Z JAEA-14](#)
[TOI \(Se\)](#)
[Wiki: Sm \(Z=62\)](#)
[Discovery](#)

^{129}Sm **Beta+ decay (Z=62, N=67)** **Samarium**

it is useful for experiment planning how nucleus has been discovered: beam, target, reaction, energy, location.

<https://people.nsd.msu.edu/~thoennes/isotopes/abstracts/62-samarium/62-Sm-129.pdf>

<https://people.nsd.msu.edu/~thoennes/isotopes/>

Discovery of Nuclides Project

Michael Thoennesen

News: 280Ds discovered

January 23, 2021

Yesterday, the first isotope of 2021 was discovered. Samark-Roth et al. reported the first observation of 280Ds in the paper "Spectroscopy along Flerovium Decay Chains: Discovery of 280Ds and an Excited State in 282Cn" in *Phys. Rev. Lett.* **126** (2021)

Video

- 2012 Timeline Movie
- 2015 Timeline Movie
- 2018 Timeline Movie

Other links

^{129}Sm

Xu et al. first identified ^{129}Sm in 1999 and reported the results in "New β -delayed proton precursors in the rare-earth region near the proton drip line" [1]. A 165 MeV ^{36}Ar beam was accelerated with the Lanzhou sector-focused cyclotron and bombarded an enriched ^{96}Ru target. Proton- γ coincidences were measured in combination with a He-jet type transport system. "A 134-keV γ line found in the proton coincident $\gamma(x)$ -ray spectrum in the $^{36}\text{Ar}+^{96}\text{Ru}$ reaction was assigned to the γ -ray transition between the lowest-energy 2^+ state and 0^+ ground state in the 'daughter' nucleus ^{128}Nd of the βp precursor ^{129}Sm ."

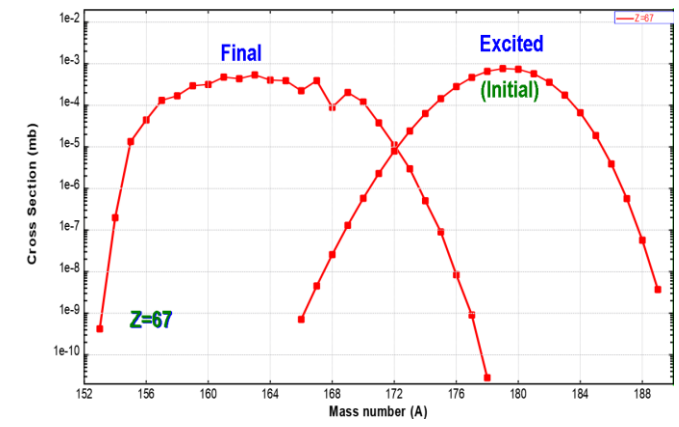
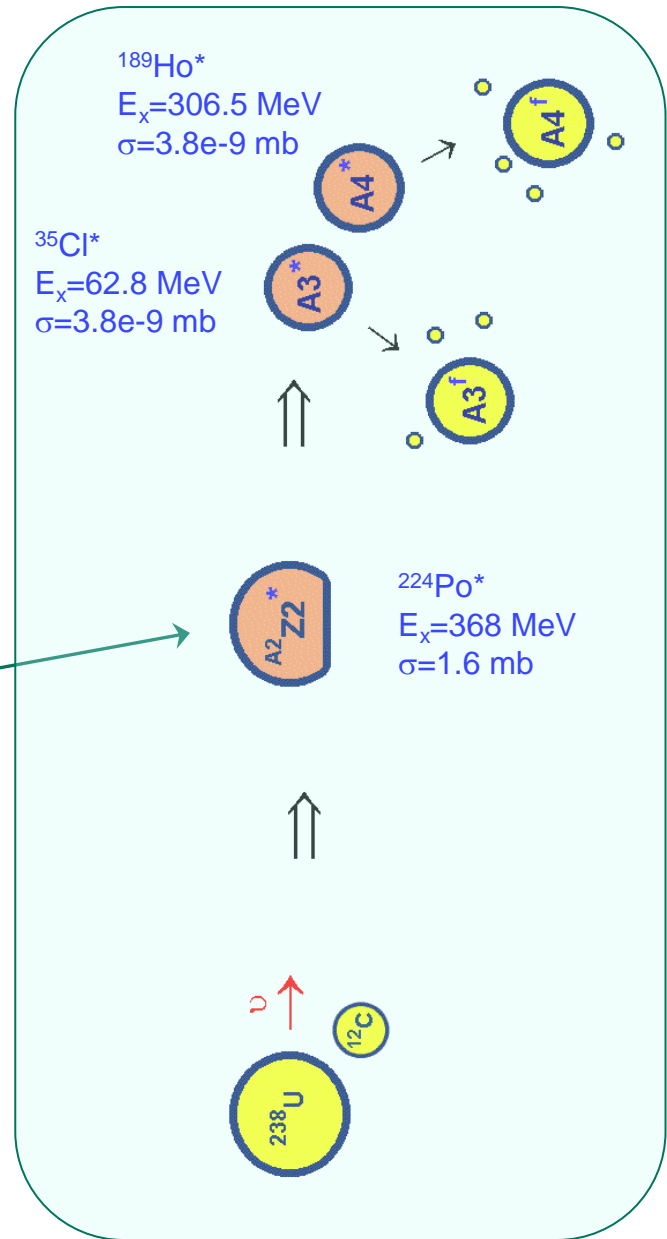
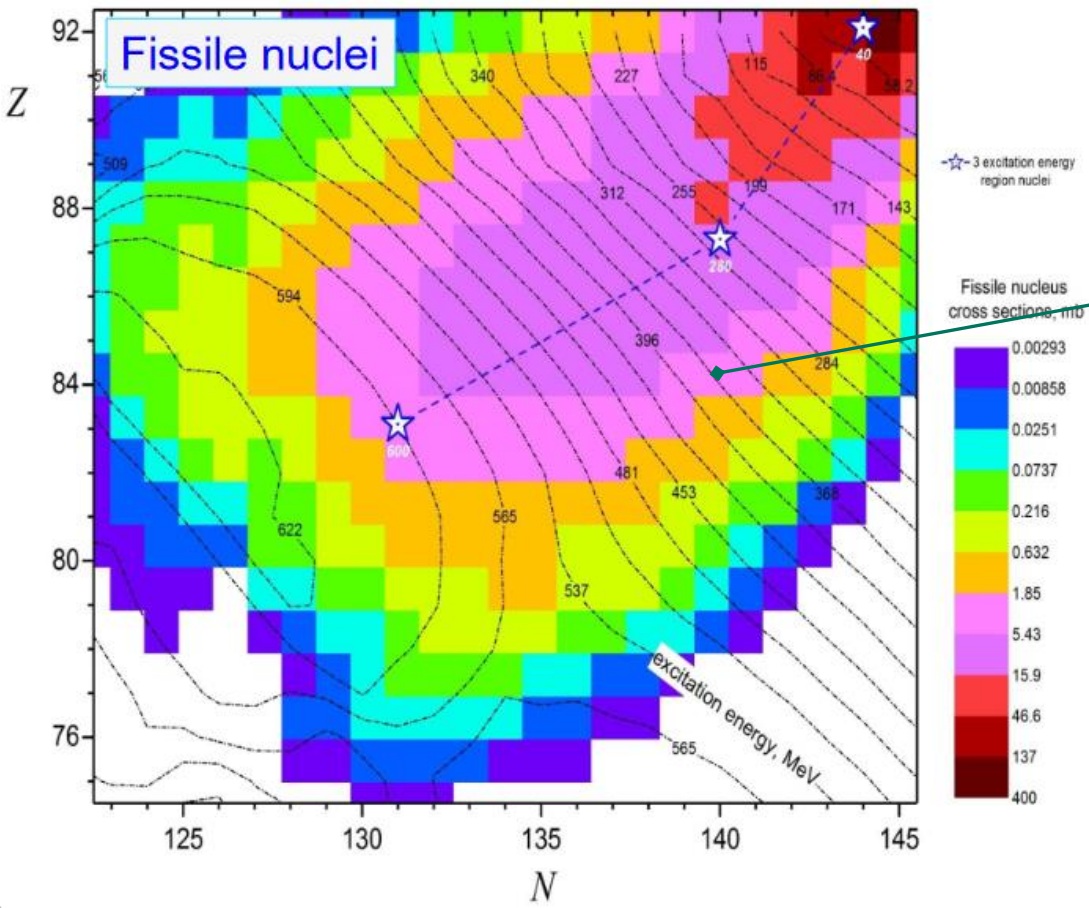
[1] S.-W. Xu *et al.*, *Phys. Rev. C* 60 (1999) 061302.

Adapted from E. May and M. Thoennesen, *At. Data Nucl. Data Tables* **99** (2013) 1

❖ Needs in detailed information

LISE⁺⁺ Abrasion-Ablation model calculation

- Fissile nuclei after abrasion of ²³⁸U by ¹²C target
- Colors : cross-section
- Contours : excitation energy

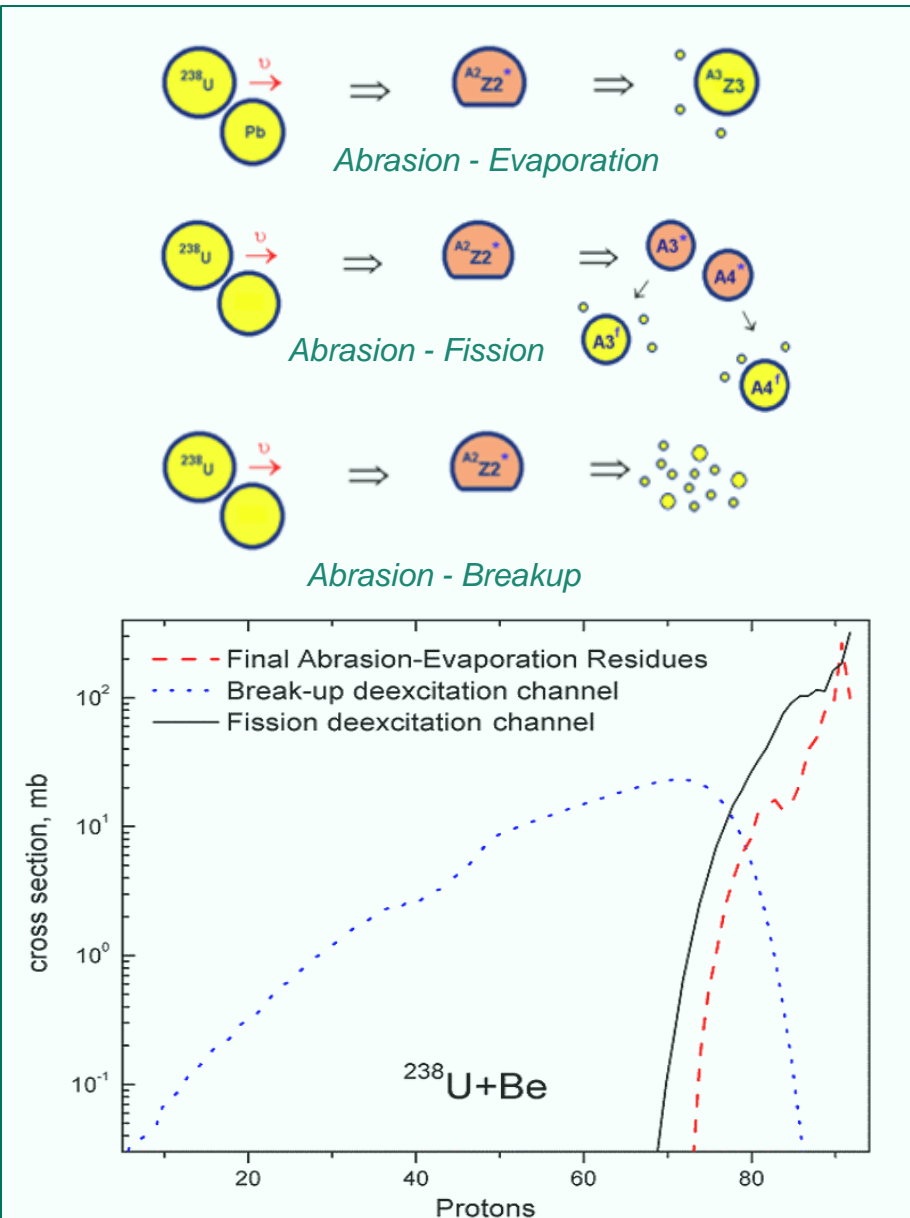


Decreasing excitation energy by 10% shifts ¹⁸⁹Ho de-excitation distribution by ~1.3 neutrons

Excitation energy variation makes large impact in high-Z neutron-rich production cross-sections

Experimental data measurement (cross sections, neutron multiplicity?) and theoretical study are required to obtain an excitation energy function in order to improve fast Abrasion-Fission models.

❖ Needs in detailed information



The “limiting” temperature defines the breakup stage (multifragmentation)

LISE++ Abrasion-Ablation uses $T=f(A)$






Break-up parameters													
The limiting temperature calculated from the curve based on three points for masses 50,150,250	<table border="0"> <tr> <td>T (A=050)=</td> <td><input type="text" value="8"/></td> <td>8.0</td> </tr> <tr> <td>T (A=150)=</td> <td><input type="text" value="5.9"/></td> <td>5.9</td> </tr> <tr> <td>T (A=250)=</td> <td><input type="text" value="4.7"/></td> <td>4.7</td> </tr> <tr> <td>Diffuseness=</td> <td><input type="text" value="0.05"/></td> <td>0.05</td> </tr> </table>	T (A=050)=	<input type="text" value="8"/>	8.0	T (A=150)=	<input type="text" value="5.9"/>	5.9	T (A=250)=	<input type="text" value="4.7"/>	4.7	Diffuseness=	<input type="text" value="0.05"/>	0.05
T (A=050)=	<input type="text" value="8"/>	8.0											
T (A=150)=	<input type="text" value="5.9"/>	5.9											
T (A=250)=	<input type="text" value="4.7"/>	4.7											
Diffuseness=	<input type="text" value="0.05"/>	0.05											
Default values from Zi.Li & M.Liu, PRC69, 034615 (2004), Fig.5													

GSI Abra-Abla uses $T=f(Z, \langle N/Z \rangle)$

Determination of the Freeze-Out Temperature by the Isospin Thermometer
 P. Napolitani, et al., Physics of Atomic Nuclei volume 66, pages 1471–1477 (2003)

- ❑ Experimental study of abrasion mechanism:
 - measurement of fragment production cross section for all channels
 - excitation energy determination
 - temperature determination
- ❑ Theoretical study

Data

- Atomic Masses 
- Isomeric states database 
- Fission barrier database 
- Experimental production cross sections 
- Experimental fragment momentum distributions 

Reactions with exotic nuclei

Needs for detailed information

- Excitation energy of (fissile) nuclei after abrasion
- Limiting temperature