



Oleg B. Tarasov

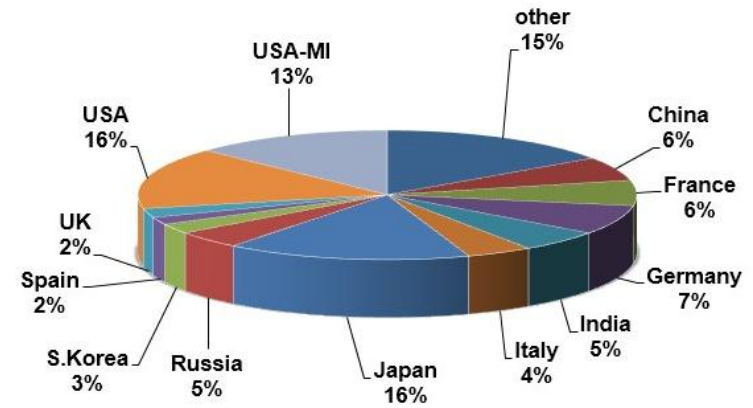


LISE<sup>++</sup> : EXOTIC BEAM PRODUCTION WITH FRAGMENT SEPARATORS

□ The LISE++ program is designed

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

The LISE++ code geography



**Projectile Fragmentation Table:**

Element	47Ti	43Ti	44Ti	45Ti	46Ti	47Ti	48Ti	49Ti	50Ti
47Sc									
48Sc									
49Sc									
40Ca									
41Ca									
42Ca									
43Ca									
44Ca									
45Ca									
46Ca									
47Ca									
48Ca									
39K									
40K									
41K									
42K									
43K									
44K									
45K									
46K									
47K									
38Ar									
39Ar									
40Ar									
41Ar									
42Ar									
43Ar									
44Ar									
45Ar									
46Ar									
37Cl									
38Cl									
39Cl									
40Cl									
41Cl									
42Cl									
43Cl									
44Cl									
45Cl									
36S									
37S									
38S									
39S									
40S									
41S									
42S									
43S									
44S									
35p									
36p									
37p									
38p									
39p									
40p									
41p									
42p									
43p									
34Si									
35Si									
36Si									
37Si									
38Si									
39Si									
40Si									
41Si									
42Si									
43Si									
44Si									
33Al									
34Al									
35Al									
36Al									
37Al									
38Al									
39Al									
40Al									
41Al									
42Al									
43Al									

**dE-TKE Plot:** Energy loss (MeV) vs Total energy (MeV) for  $^{40}\text{Ar}$  (50.0 MeV/u) + Ta (100  $\mu\text{m}$ ). Settings on  $^{36}\text{Ar}$ ; Config: DWDMMMMMM dp/p=4.05%; Wedges: Al (100  $\mu\text{m}$ ); Brho(Tm): 1.855, 1.7893; 1st TKE detector: Material 3 \* dE: Material 3 - Si (350  $\mu\text{m}$ ).

**Physical calculator window:**

Block	Z	Thickness	MeV/u	MeV	MeV	<Q>
Material 1	Si	300 micron	0	0	431.91	0.00
Material 2	Si	250 micron	0	0	0	0
Material 3	Si	350 micron	0	0	0	0
Material 4	Si	500 micron	0	0	0	0
Material 5						
Material 6						
Material 7						

Projectile Fragmentation, Fusion-Evaporation, Fusion-Fission, Coulomb Fission, and Abrasion-Fission models

Production Mechanism

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

48Ca(140.0 MeV/u) + Be -> 42S

*Projectile fragmentation*  
A1 > A2 ≥ A3

Reactions

additionally calculate yields for the next reactions

- Projectile Fragmentation
- Fusion -> Residual
- Fusion -> Fission
- Coulomb fission
- Abrasion-Fission
- Two Body Reactions
- ISOL mode

Make default

OK  Cancel  Help

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

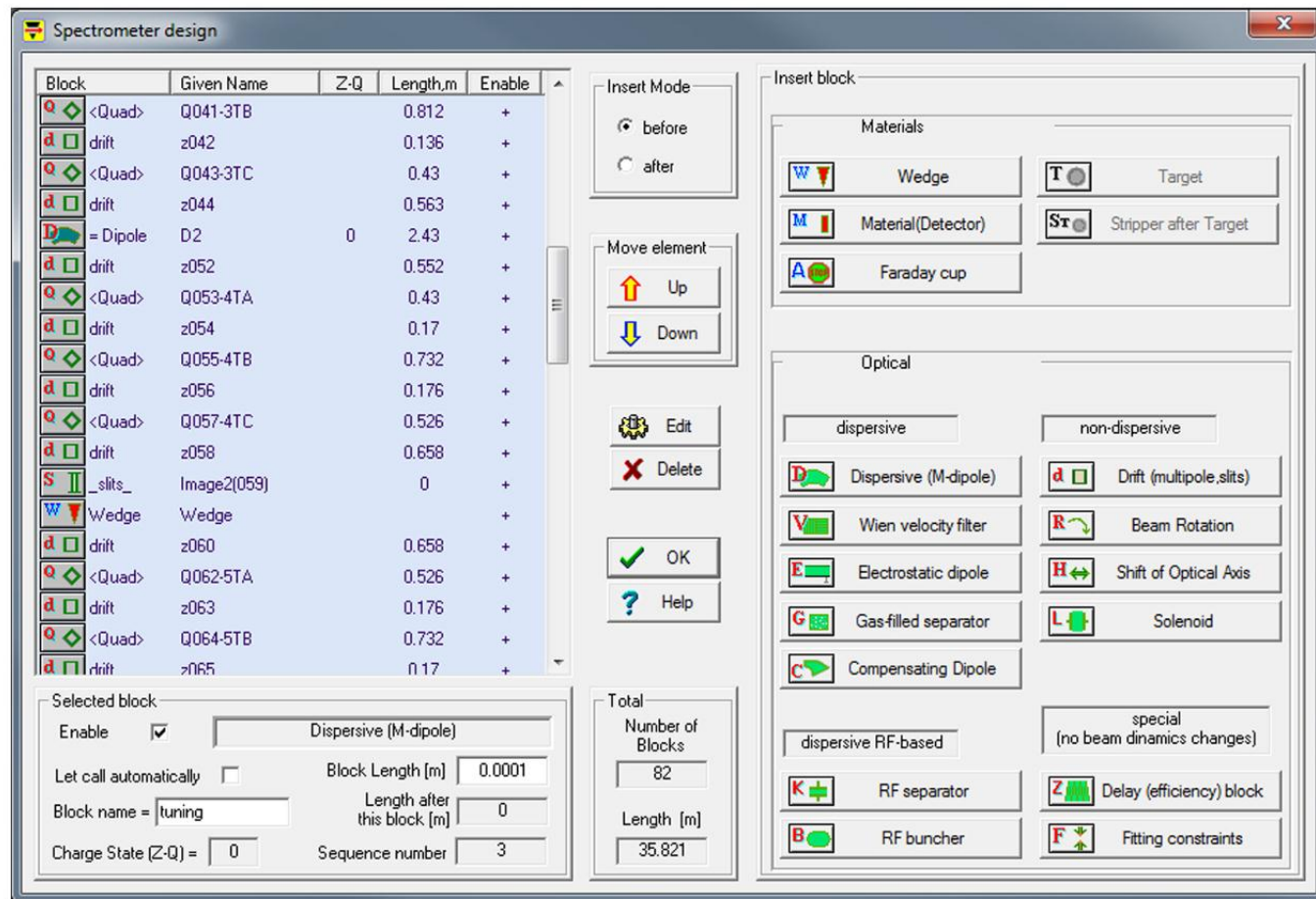
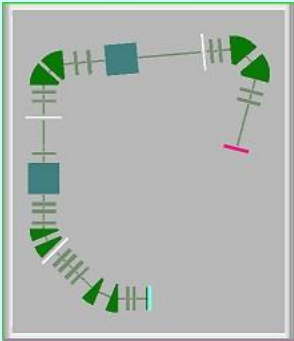
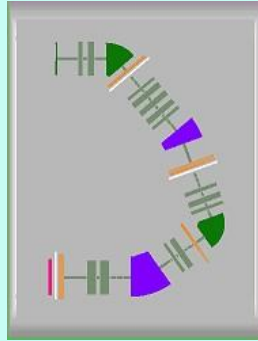


Fig. 1. Updated view of the "Spectrometer Design" dialog window.

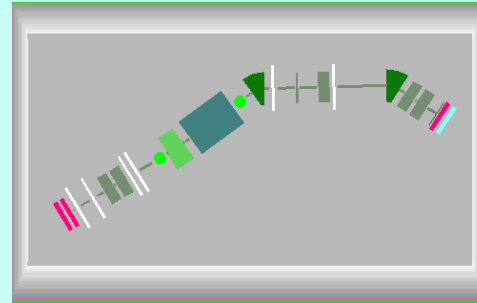
Includes *extended* configurations of separators at NSCL/MSU, RIKEN, GANIL, GSI, FLNR/JINR, TAMU, TRIUMF, ANL and others.



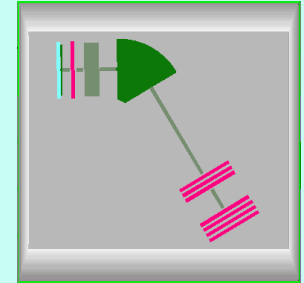
SECAR, *MSU*



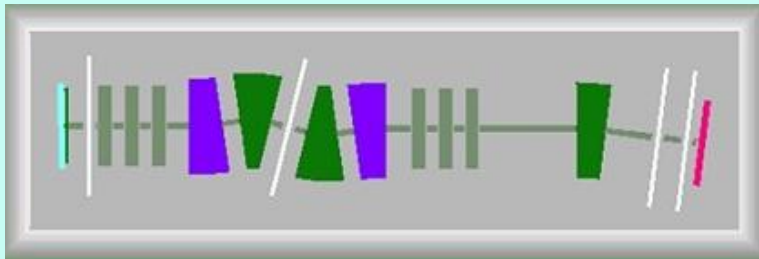
DRAGON, *Canada*



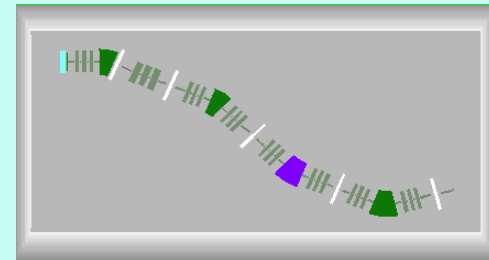
MARS, *TAMU*



PRISMA, *Italy*



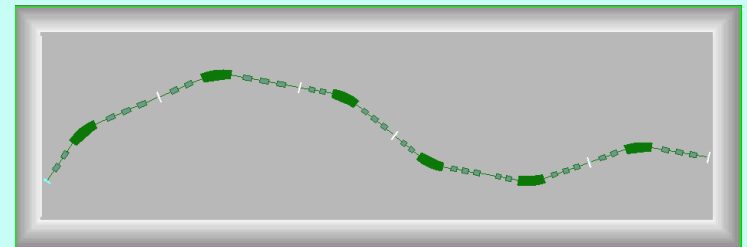
SHELS, *Russia*



S<sup>3</sup>, *France*



BigRIPS+ZeroDegree, *Japan*



SuperFRS\_HEB, *Germany*



- The code is distributed free with the LISE<sup>++</sup> user license
- Official site : [lise.nsl.msui.edu](http://lise.nsl.msui.edu)
- Current version 9.10.342, 09-Aug-2016

- Version 10 will be released soon
- Current operating system : MS Windows
- Currently porting to new framework : cross platform & parallel computing

## Built-in powerful tools:

- Monte Carlo simulation of fragment transmission,
- Monte Carlo simulation of fission fragment kinematics,
- Ion Optics calculation and Optimization (*new*),
- LISE for Excel (MS Windows, Mac OS - download)

## *LISE<sup>++</sup> calculators:*

- «Physical Calculator»,
- «Relativistic Kinematics Calculator»,
- «Evaporation Calculator»,
- «Radiation Residue Calculator» (*new*),
- «Ion Mass calculator" (*new*),
- «Matrix calculator"

## *Implemented codes:*

- «PACE4» (fusion-evaporation code),
- «MOTER» (raytracing-type program for magnetic optics),
- «ETACHA4» (charge-state distribution code) (*new*),
- «Global» (charge-state distribution code),
- «Charge» (charge-state distribution code),
- «Spectroscopic Calculator" (of J.Kantele»)

## *LISE<sup>++</sup> Utilities:*

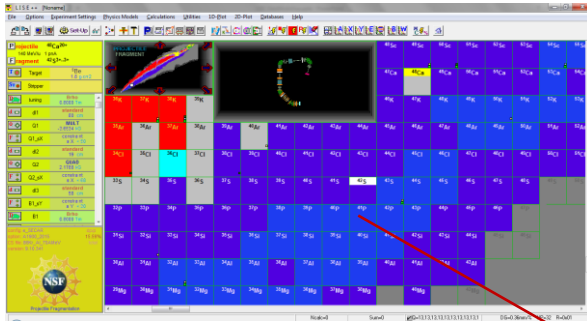
- Stripper Foil Lifetime Utility,
- Brho Analyzer,
- Twinsol (solenoid) utility,
- Units Converter,
- ISOL Catcher,
- Decay Analysis (includes Proton, Alpha, Cluster, Sp.Fission half-lives calculation),
- Reaction Utilities (Characteristics, Converters, Plots),
- «BI»- the automatized search of two-dimensional peaks in spectra

## *Databases:*

- Nuclide and Isomeric State databases with utilities,
- Large Set of Calculated Mass Tables (includes FRIB mass tables),
- Ionization Energy database (used with the Ion Mass calculator),
- Decay Branching Ratio database (used with the Radiation Residue calculator),

permit to work well below this energy limit, and this makes the program very attractive for all users dealing with physics of heavy ions from 10 keV up to some GeV per nucleon.

## Throw the Table of nuclides



## Throw the Menu

**Databases Help**

- AME & properties: View, Edit
- AME & properties: Plots
- Isomer database
- Ionization energy database
- Decay Branching Ratio database

- S 1n
- S 2n
- S 1p
- S 2p
- Q alpha
- Beta- decay
- Beta+ decay
- T 1/2
- Mass Excess
- Binding energy
- Binding energy per A
- S d
- S 3He
- S t
- "Stability" plot
- P (pairing energies)
- D (separation energy derivatives)

**statistics: 41S**

**41S      Beta- decay (Z=16, N=25)      Sulfur**

---











AME2012 index	16025	error
Mass excess, [MeV]	-19.0086	0.0041
Binding energy	337.4136	0.0041
Beta- decay	8.2986	0.0688
Beta+ decay	-14.0288	0.0802
S (2n)	11.9889	0.0502
S (2p)	35.9069	0.0905
Q (alpha)	-14.8392	0.0831
S (n)	4.2421	0.0057
S (p)	18.2231	0.1113
T 1/2	1.99 sec	0.05

Q-reaction (b+t -> f1+f2) -9.13 MeV (error=0.0041 MeV)

---

No user cross sections were found for this isotope

- LISE++ database
- Decay analysis
- Branching Ratio
- Z-wallet NNDC
- A, Z NNDC
- A, Z JAEA-10
- A, Z TOrl [Se]
- Chemistry - S
- Discovery

- Atomic Masses 
- Ionic Masses 
- Isomeric states database 
- Fission barrier database 
- Experimental production cross sections 
- Decay branching ratio database 
- Compound material database 
- Discovery database 
- ..... (*ranges, model parameterization, and so on*)
  
- Set of separator configurations /LISE/ 
- NSCL & FRIB secondary beam rates /LISE/ 

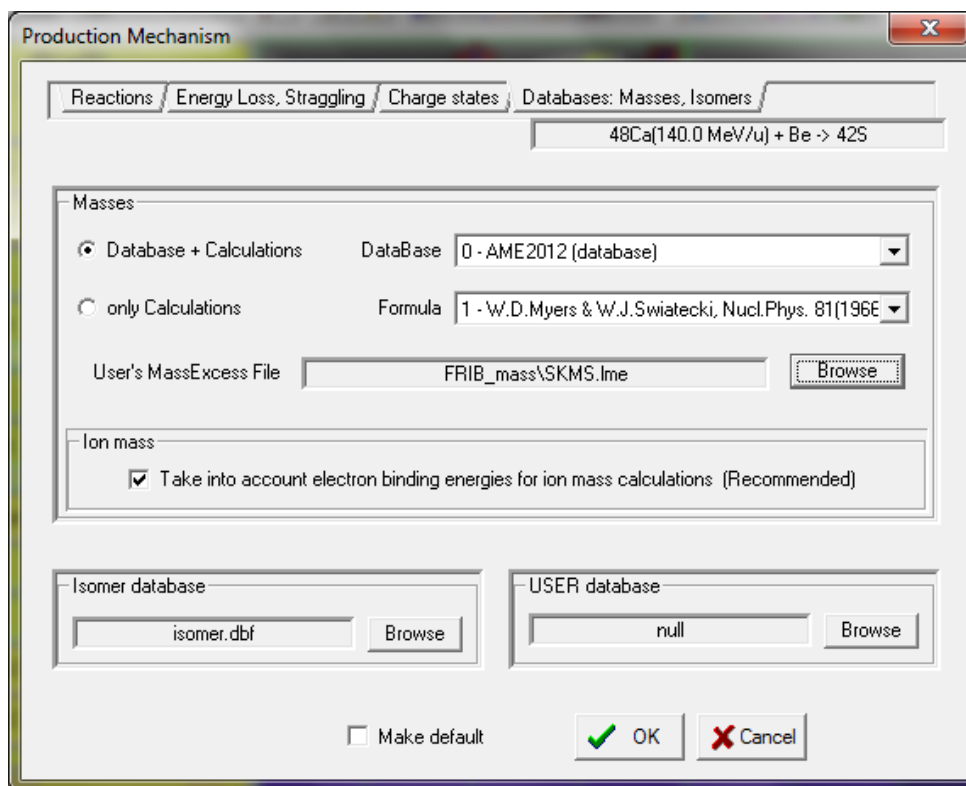


- Ion mass for **optics settings**, isotope selection
- **Production rates** with built-in reaction models (separation energies in the case of abrasion-ablation, fusion-residues, all fission reactions)
- Half-life calculation, decay analysis
- Plotting isotope properties (energy separation, binding energies,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

LISE++ built-in mass excess files

```

\AME2003.lme
\AME2011.lme
\AME2011+GXPF1B.lme
\AME2011+GXPF1B5.lme
\AME2012.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
\hfb17.lme
\hfb8.lme
\hfb9.lme
\ktuy.lme
\Moller95.lme
\zero.lme
    
```



What is about fast experimental masses update ?

❑ 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)

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

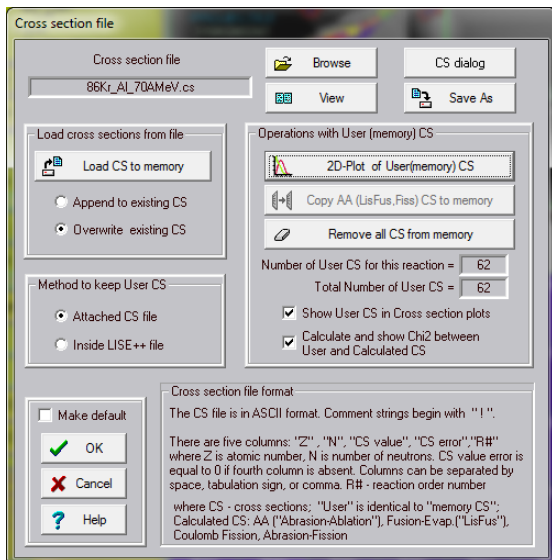
- v.9.8.114      atomic mass was used      238.0508 amu
- v.9.8.117      correction for e- masses      238.0003 amu
- v.9.10.131    correction for e- binding energies    238.0011 amu

**Atom & Ion Masses**

Charge State	Ground shell configuration	Total binding energy [keV]	Mass	
			amu	GeV
Q=0 atom	[Rn] 5f3.6d.7s2	761.513	238.05079	221.742896
Q= 7	[Hg] 6p5	761.244	238.04695	221.739319
Q=Z full stripped		0.000	238.00114	221.696645

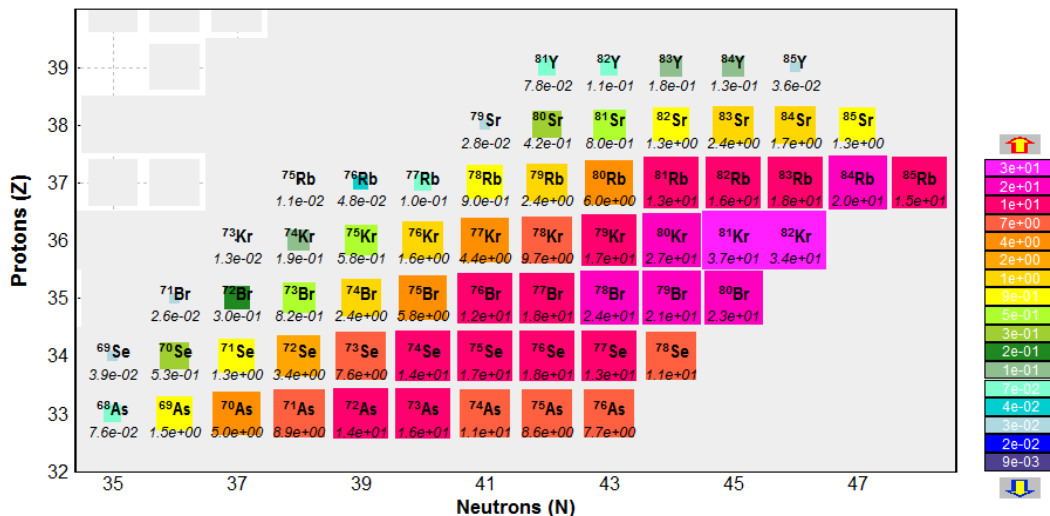
  

Shl	Z	Q	IsoelSeq	Ground Shells	Ioniz_Energy	Total BE
7	92	0+	U	[Rn] 5f3.6d.7s2	0.0062	761.513
7	92	1+	Pa	[Rn] 5f3.7s2	0.0116	761.507
5	92	2+	Th	[Rn] 5f4	0.0198	761.495
5	92	3+	Ac	[Rn] 5f3	0.0367	761.476
5	92	4+	Ra	[Rn] 5f2	0.046	761.439
5	92	5+	Fr	[Rn] 5f	0.06	761.393
6	92	6+	Rn	[Hg] 6p6	0.089	761.333
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] 4f14.5d10.6s2	0.21	760.567
5	92	13+	Au	[Xe] 4f14.5d10.6s	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
5	92	26+	Dy	[Cd] 4f14.5p4	0.8	754.129
5	92	27+	Tb	[Cd] 4f14.5p3	0.84	753.329
5	92	28+	Gd	[Cd] 4f14.5p2	0.93	752.489



## Cross-sections

Pfaff-96 Thesis : Isotopic cross sections from 86Kr + 27Al at 70 MeV/nucleon  
Z N CS dCS React



A lot of complains...

	Common Name	Atomic Stoich.	Density	Cancel
Nuclear physics materials	Aluminum Oxide alpha	Al2 O3	3.98	Input
Plastic-Polimers	Bakelite	H9 C9 O1	1.45	Input
Liquids	1-2 - Ethanediol	H6 C2 O2	1.1088	Input
Gases	1-2 Difluorethane	H4 C2 F2	0.0012	Input
	1-2 Difluorethane	H4 C2 F2	0.0012	
	1-2 Difluorethane	H2 C2 F2	0.0012	
	1-3-Butadiene	H6 C4	0.0012	
	Acetylene	H2 C2	0.0012	
	Air	O23 N76 Ar1	0.0012	
	Allene Propadiene	H4 C3	0.0012	
	Ammonia	H3 N1	0.0012	
	Butane	H10 C4	0.0012	
	Carbon Dioxide	C1 O2	0.0012	
	Carbon Tetrafluoride	C1 F4	0.0012	
	Cyclobutane	H8 C4	0.0012	
	Cyclopropane	H6 C3	0.0012	
	Cyclopropene	H4 C3	0.0012	
	Ethane	H6 C2	0.0012	
	Ethane - Hexafluoride	C2 F6	0.0012	
	Ether Dimethyl	H6 C2 O1	0.0012	
	Ethylene	H4 C2	0.0012	
	Ethylene Sulfide	H4 C2 S1	0.0012	
	Hydrogen Sulfide	H2 S1	0.0012	
	Methane	H4 C1	0.0012	
	Methane Chloro-Tri. Freongas	C1 F3 CL1	0.0012	
	Methane Dichloro-Di. Freon-12	C1 F2 CL2	0.0012	
	Methane Dichloro-Fl. Freon-21	H1 C1 F1 CL2	0.0012	

Should be paid more attention for gases including pressure & temperature values for the next user recalculation as it was done for the molecular case.

**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)

Use in the code

Use in the code	Fission Barrier at L=0	Fission Barrier at Lx = 10	G.S. Energy at Lx (MeV)
<input type="radio"/> 0 - "Barfil" -> invalid for this isotope(A,Z)	3.78		
<input checked="" type="radio"/> 1 - "FisRot" - S.Cohen et al.,An.P 82(1974)	5.07	4.88	0.32
<input type="radio"/> 2 - LDM - W.Myers ,W.Swiatecki,NP81(1966)	5.56		
<input type="radio"/> 3 - FILE: A.Mamdouh et al,NPA679(2001)337	5.3		
<input type="radio"/> 4 - FILE: Experimental barriers			
<input type="radio"/> 5 - FILE: P.Moller et al.,LANL-UR-08-4190	5.87		
<input type="radio"/> 6 - FILE: P.Moller et al., PRC91(2015)024310	5.87		

For models # 0,1,2

Barfac = 6 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

	default
for Protons	9.0 MeV
for Neutrons	2.5 MeV

For models # 3,4

if FILE data are absent then use LDM model #

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

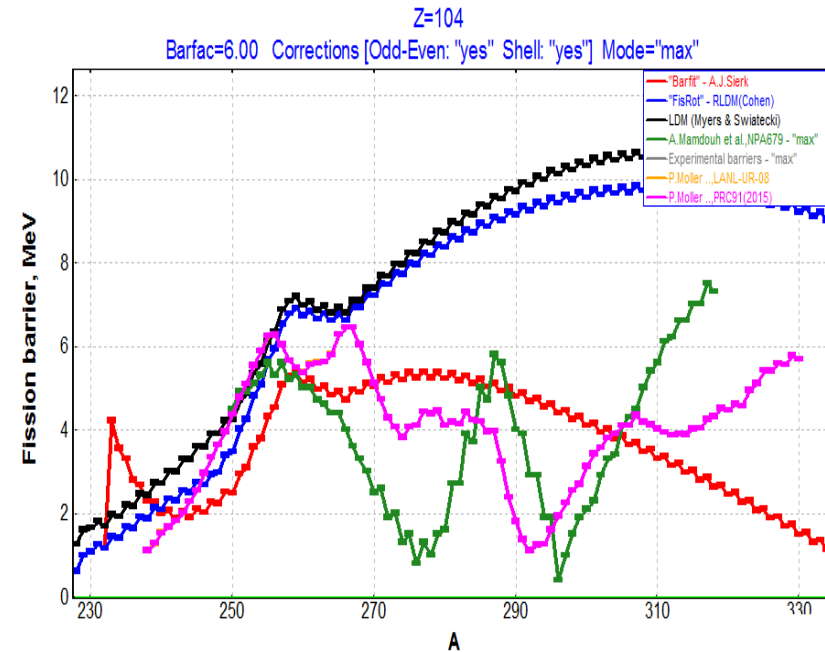
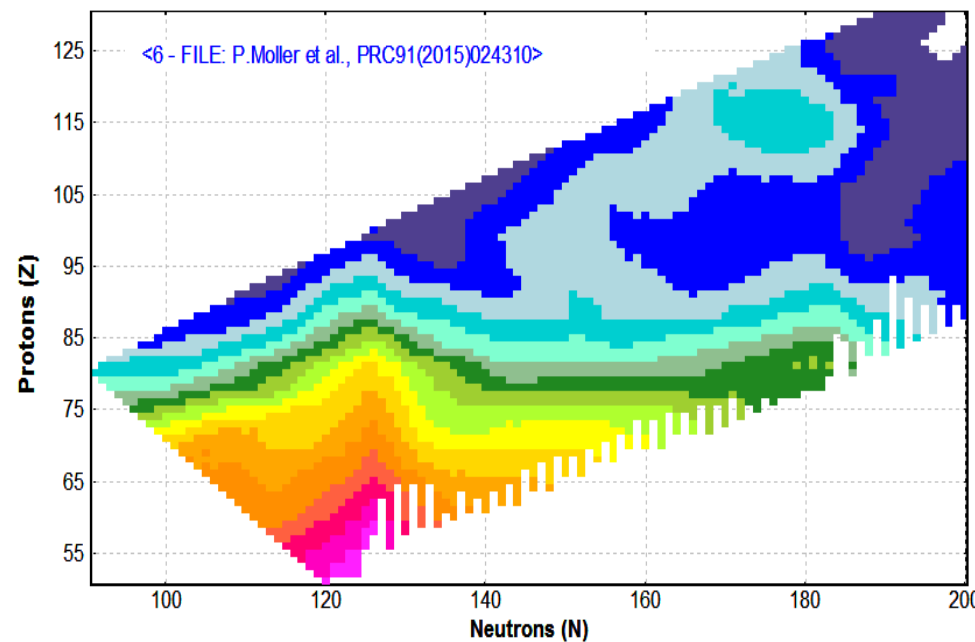
1. Fission Barrier Plot: f(L)  
2. Yrast Line

Ok Cancel Help Make default

See Walter's talk

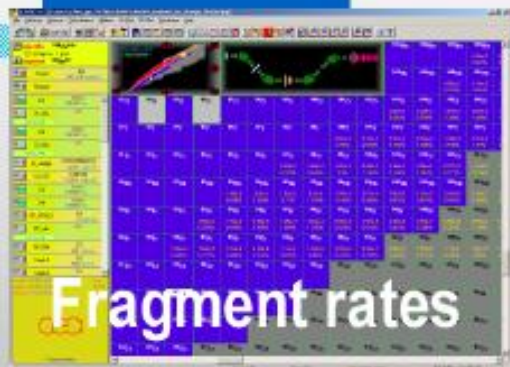
SHE vs. barriers

Fission barrier





It will be nice to simulate...

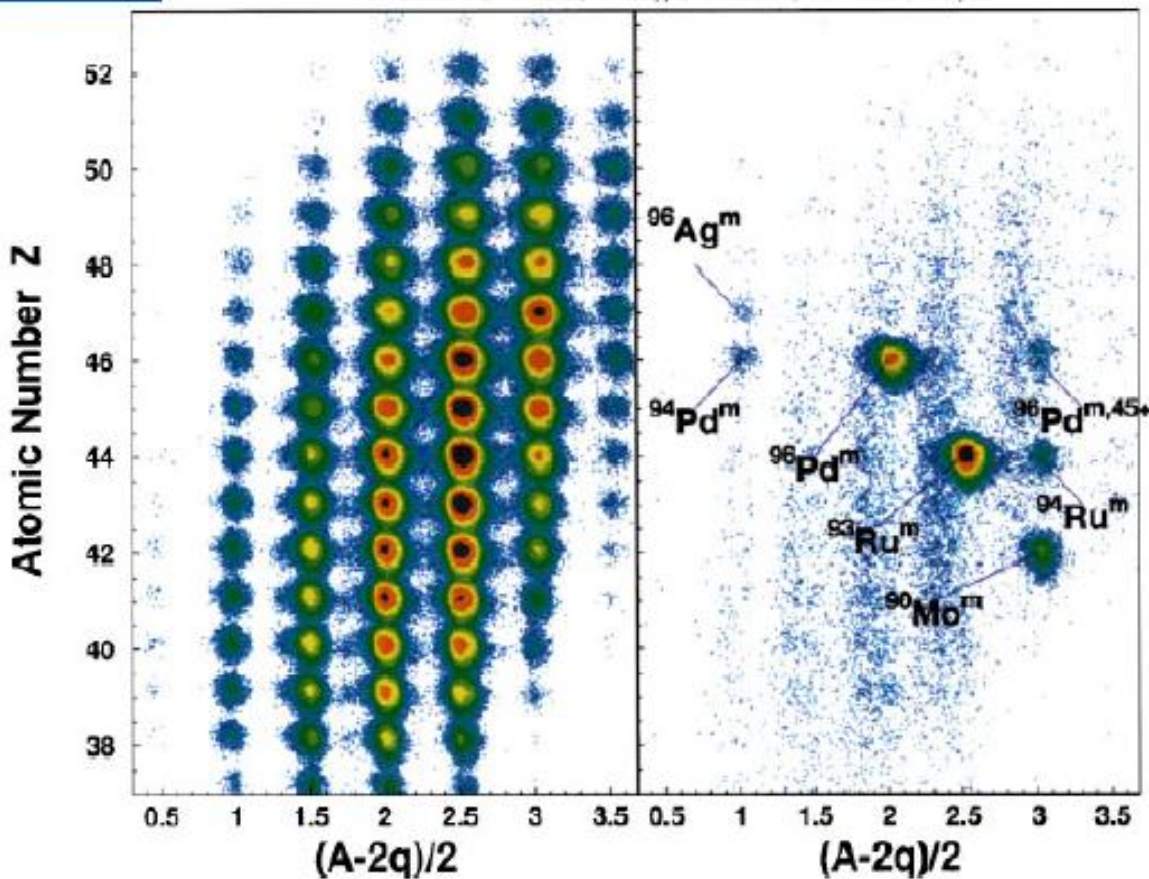


LISE++  
γ-database

γ-registration  
settings

## New $\mu$ s isomers in $T_z=1$ nuclei produced in the $^{112}\text{Sn}(63.4 \text{ MeV}) + ^{64}\text{Ni}$ reaction

R. Grzywacz,<sup>1,2</sup> R. Anne,<sup>2</sup> G. Auger,<sup>2</sup> C. Borcea,<sup>3</sup> J. M. Corre,<sup>2</sup> T. Dörfler,<sup>4</sup> A. Fomichev,<sup>5</sup> S. Grevy,<sup>6</sup> H. Grawe,<sup>7</sup> D. Guillemaud-Mueller,<sup>3</sup> M. Huyse,<sup>8</sup> Z. Janas,<sup>7</sup> H. Keller,<sup>7</sup> M. Lewitowicz,<sup>2</sup> S. Lukyanov,<sup>5,2</sup> A. C. Mueller,<sup>6</sup> N. Orr,<sup>9</sup> A. Ostrowski,<sup>2</sup> Yu. Penionzhkevich,<sup>5</sup> A. Piechaczek,<sup>8</sup> F. Pougheon,<sup>8</sup> K. Rykaczewski,<sup>1,10</sup> M.G. Saint-Laurent,<sup>2</sup> W. D. Schmidt-Oil,<sup>4</sup> O. Sorlin,<sup>6</sup> J. Szerypo,<sup>1</sup> O. Tansov,<sup>3,2</sup> J. Wauters,<sup>8</sup> J. Zylicz<sup>1</sup>



Color identification plot of all nuclei observed (left panel) and those in correlation with gamma radiation (right panel). The  $(A-2q)/2$  variable is equal to the  $T_z$  of the nucleus for fully stripped ion ( $q=Z$ ). A symbol “ $^{96m}\text{Pd}^{45+}$ ” denotes  $^{96m}\text{Pd}$  nuclei transmitted and detected as a hydrogen like ions.



# $\mu$ s Isomeric states - powerful particle identification tool

## LISE++ simulations

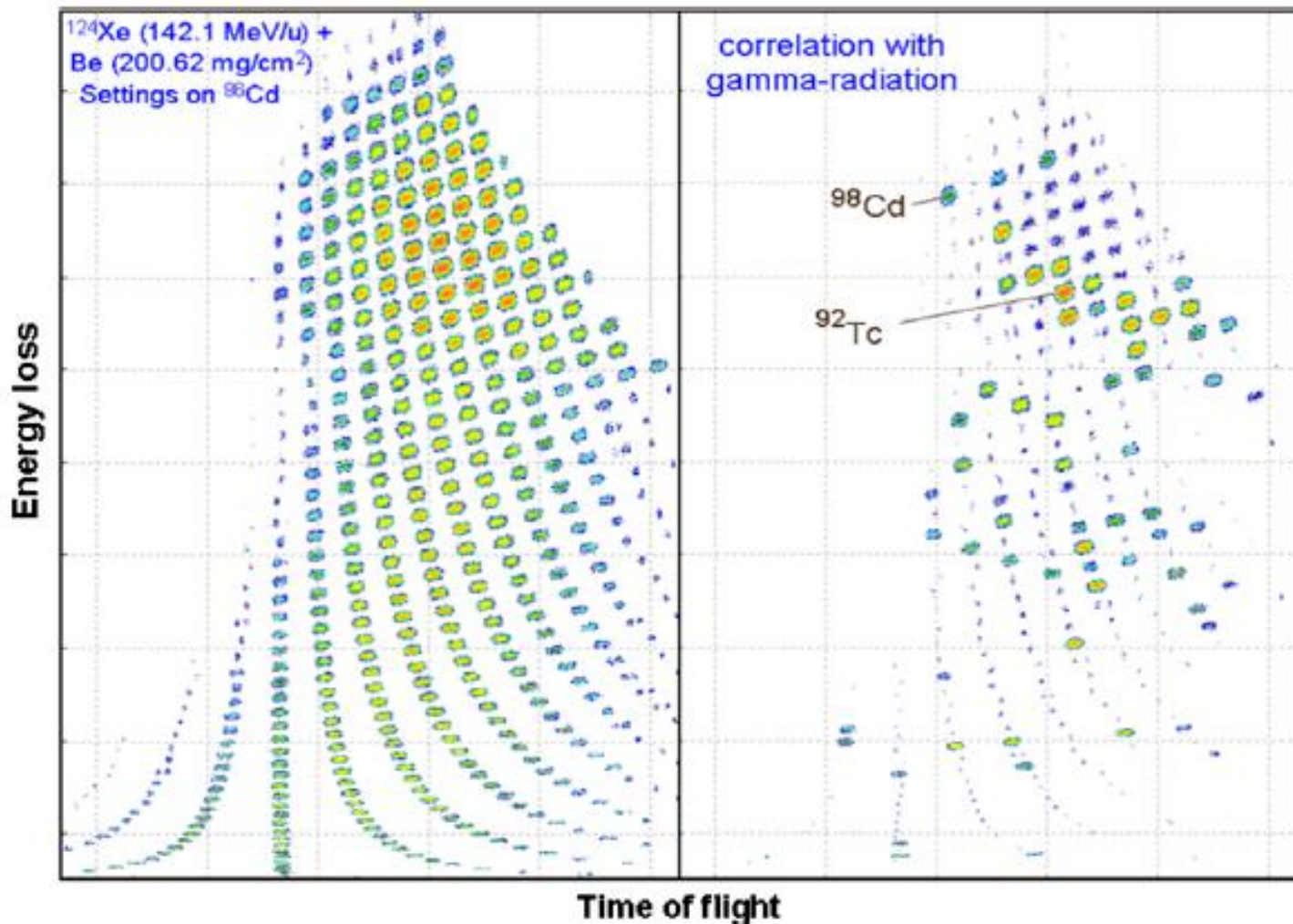


Fig. 2. LISE++ identification plot of all nuclei produced in the reaction  $^{124}\text{Xe} + \text{Be}$  (left panel) and those in coincidence with gamma-radiation (right panel) simulated by analogy to the work of [24] with a  $^{112}\text{Sn}$  beam.



$P_n$  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,<sup>1</sup> B. Singh,<sup>1,\*</sup> I. Dillmann,<sup>2</sup> D. Abriola,<sup>3</sup> T.D. Johnson,<sup>4</sup> E.A. McCutchan,<sup>4</sup> and A.A. Sonzogni<sup>4</sup>

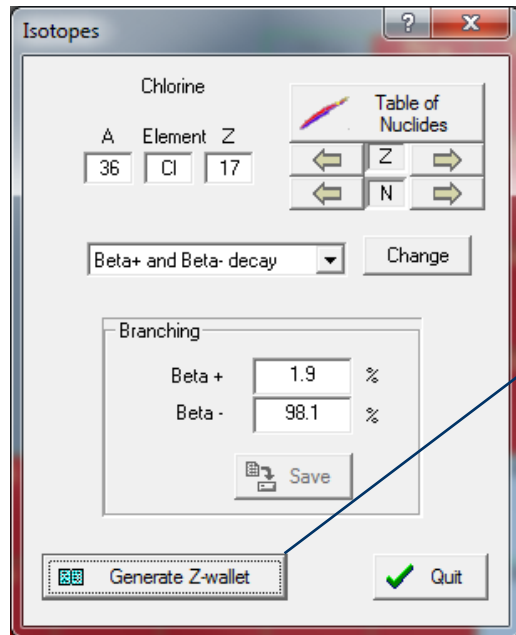
<sup>1</sup>Department of Physics and Astronomy, McMaster University, Hamilton, Ontario L8S 4M1, Canada

<sup>2</sup>TRIUMF, Vancouver, British Columbia V6T 2A3, Canada

<sup>3</sup>Department of Physics, TANDAR Laboratory, C.N.E.A., Buenos Aires, Argentina

<sup>4</sup>National Nuclear Data Center, Brookhaven National Laboratory, Upton, NY 11973-5000, USA

We present an evaluation and compilation of  $\beta$ -delayed neutron probabilities and half-lives for nuclei in the region  $Z = 2 - 28$  ( $^8\text{He} - ^{80}\text{Ni}$ ). 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  $\beta$ -delayed neutron emission is possible. The literature cut-off for this work is August 15<sup>th</sup>, 2015. Some notable cases as well as new standards for  $\beta$ -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.*

Decay Branching Ratio

Z=17 (Chlorine)

A	decay1	branch, %	decay2	branch, %	T 1/2, s	Abundance, %
30	Unknown	100			8.430e-13	
31	Beta +	100			1.500e-01	
32	Beta +	100			2.980e-01	
33	Beta +	100			2.511e+00	
34	Beta +	100			1.527e+00	
35	Stable	100				75.760
36	Beta +	1.90	Beta -	98.10	9.503e+12	
37	Stable	100				24.240
38	Beta -	100			2.234e+03	
39	Beta -	100			3.372e+03	
40	Beta -	100			8.100e+01	
41	Beta -	100			3.840e+01	
42	Beta -	100			6.800e+00	
43	Beta -	100			3.130e+00	
44	Beta -	100			5.600e-01	
45	Beta -	76.00	Beta - n	24.00	4.130e-01	
46	Beta -	40.00	Beta - n	60.00	2.320e-01	
47	Beta -	100			1.010e-01	
48	Beta -	100			2.480e-02	
49	Beta -	100			1.890e-02	
50	Beta -	100			4.400e-03	
51	Beta -	100			6.180e-03	
53	Unknown	100			2.700e-03	
55	Unknown	100			8.600e-04	

T 1/2 : compilation of experimental and calculated values.  
See the AME dialog for details

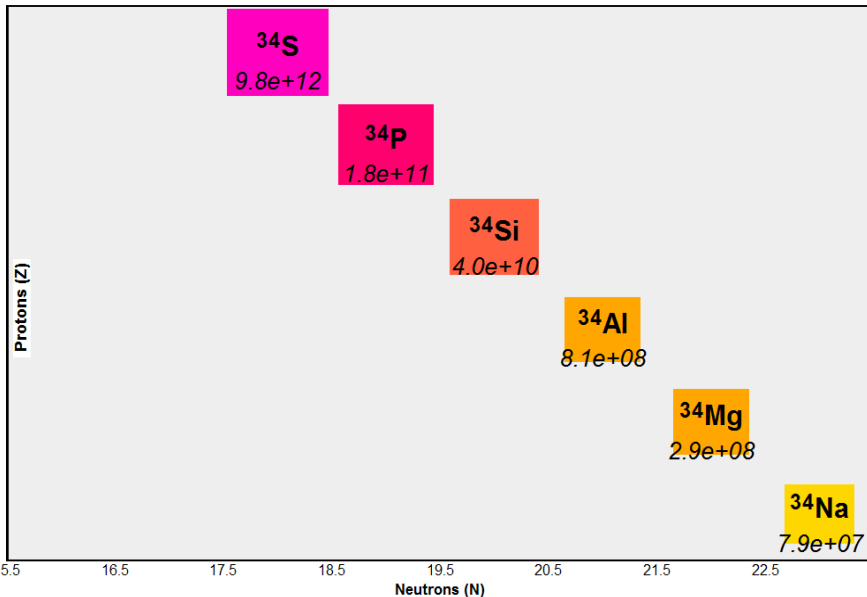
- No recommended values for  $P_n$ ?
- Non-convenient format to import
- Compilation for beta-delayed proton emission?

## v.9.10.331. No Decay Branch Database

### Radioactive decay residues

Initial isotope:  $^{34}\text{Na}$

Irradiation Time (IT) =  $1.00\text{e}+03$  sec; Decay Time (DT) =  $1.00\text{e}-06$  sec; Irr. Rate =  $1.00\text{e}+10$  pps; Plot All isotopes  
 $N_{\text{Implant}}=100$ ,  $N_{\text{Resid}}=1000$ , Abs. Error= $1.0\text{e}-11$ , Rel. Error= $1.0\text{e}-03$ , Threshold= $1.0\text{e}-10$ , Model="ODE"

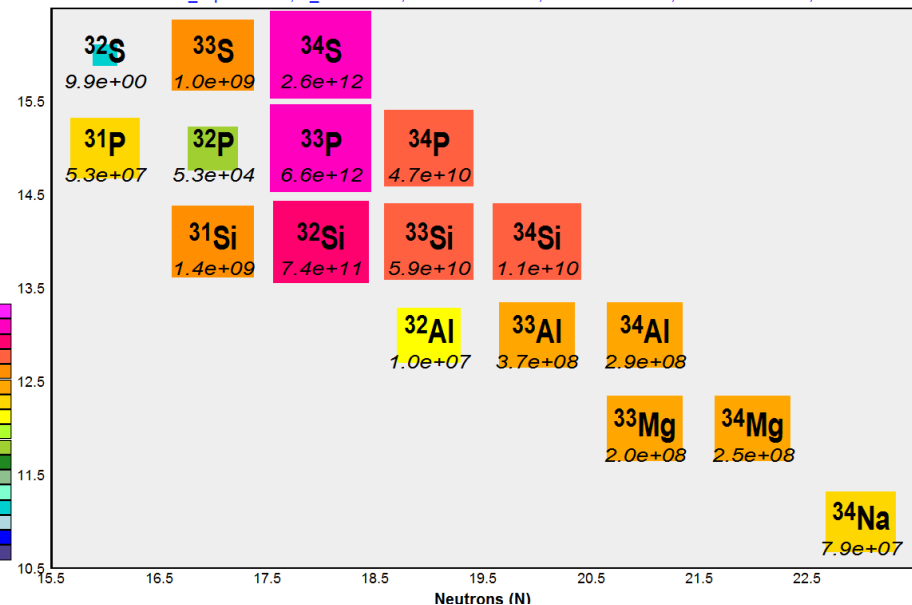


## v.9.10.341. With Decay Branch Database

### Radioactive decay residues

Initial isotope:  $^{34}\text{Na}$

Irradiation Time (IT) =  $1.00\text{e}+03$  sec; Decay Time (DT) =  $1.00\text{e}-06$  sec; Irr. Rate =  $1.00\text{e}+10$  pps; Plot All isotopes  
 $N_{\text{Implant}}=1000$ ,  $N_{\text{Resid}}=1000$ , Abs. Error= $1.0\text{e}-11$ , Rel. Error= $1.0\text{e}-03$ , Threshold= $1.0\text{e}-10$ , Model="ODE"



Sometimes it is useful for experiment planning how nucleus has been discovered: beam, target, reaction, energy (even place!)

statistics:  $^{139}\text{Dy}$

$^{139}\text{Dy}$

Discovery

### $^{139}\text{Dy}$

Xu et al. first identified  $^{139}\text{Dy}$  in 1999 and reported the results in “New  $\beta$ -delayed proton precursors in the rare-earth region near the proton drip line” [1]. A 176 MeV  $^{36}\text{Ar}$  beam was accelerated with the Lanzhou sector-focused cyclotron and bombarded an enriched  $^{106}\text{Cd}$  target. Proton- $\gamma$  coincidences were measured in combination with a He-jet type transport system. “A clear 221-keV  $\gamma$  peak and a tiny 384-keV  $\gamma$  peak in the proton-coincident  $\gamma(x)$ -ray spectrum in the  $^{36}\text{Ar}+^{106}\text{Cd}$  reaction were assigned to the  $2^+ \rightarrow 0^+$  and  $4^+ \rightarrow 2^+$   $\gamma$  transitions in the ‘daughter’ nucleus  $^{138}\text{Gd}$  of the  $\beta p$  precursor  $^{139}\text{Dy}$ .”

[1] S.-W. Xu, Z. K. Li, Y.-X. Xie, Q.-Y. Pan, Y. Yu, J. Adam, C.-F. Wang, J.-P. Xing, Q.-Y. Hu, S.-H. Li, H.-Y. Chen, T.-M. Zhang, G.-M. Jin, Y.-X. Luo, Y. E. Penionzhkevich, Y. Gangrsky, Phys. Rev. C 60 (1999) 061302.

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