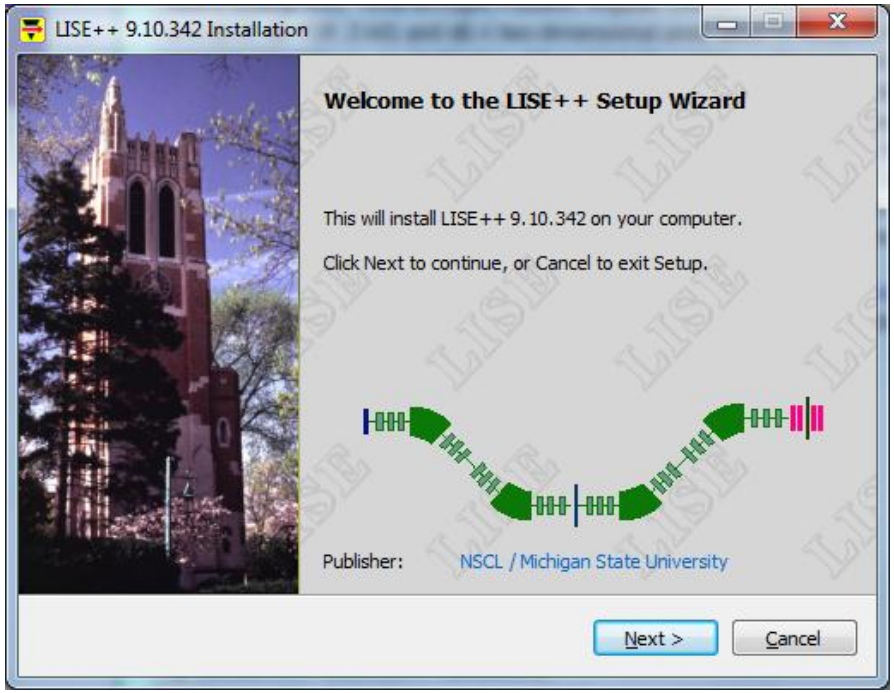
Nuclear Data Needs for LISE++

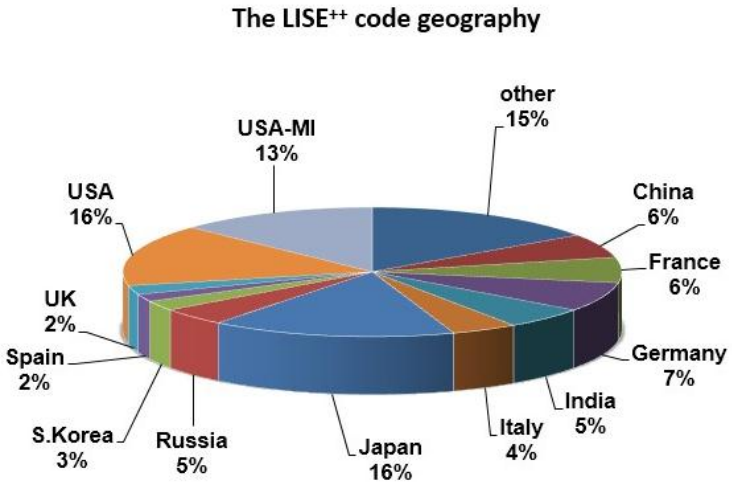
Oleg B. Tarasov

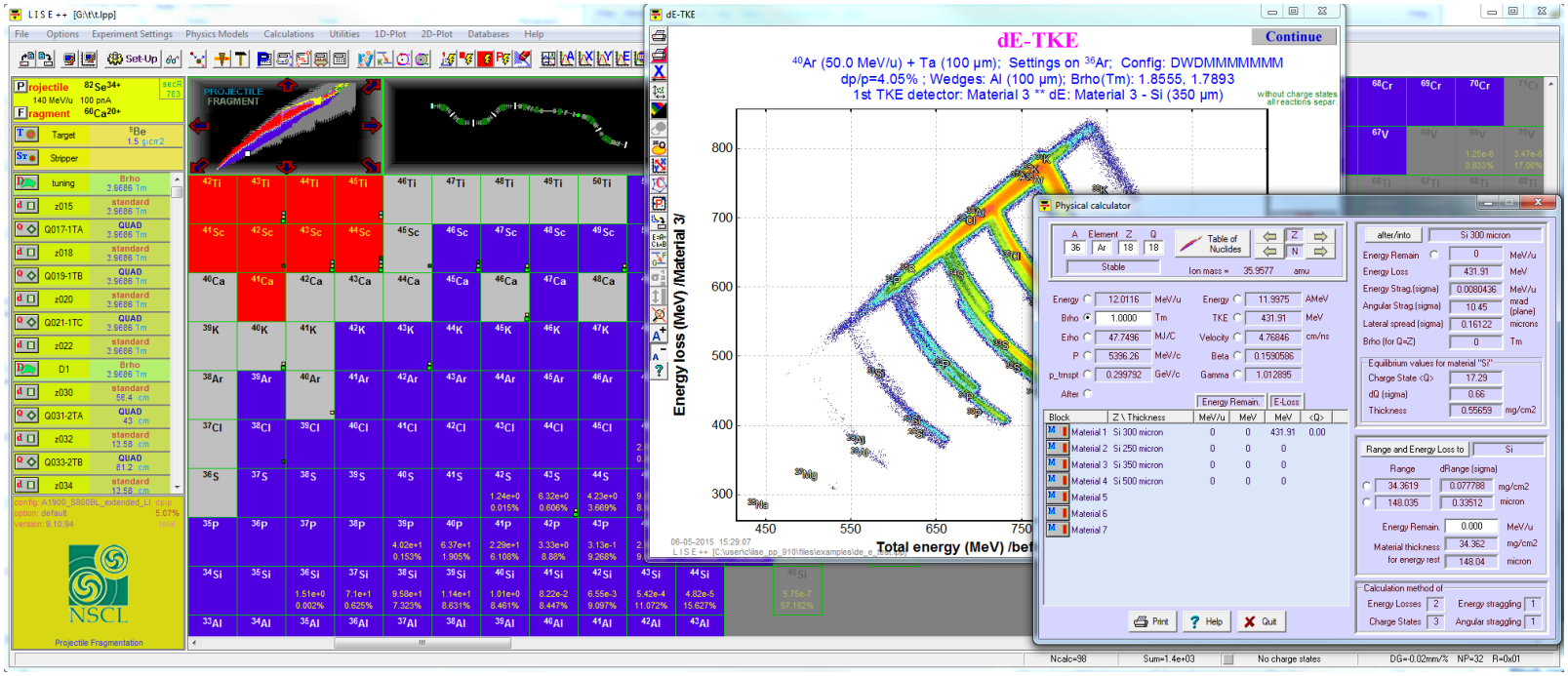


LISE++ : Exotic Beam Production with Fragment Separators

Introduction

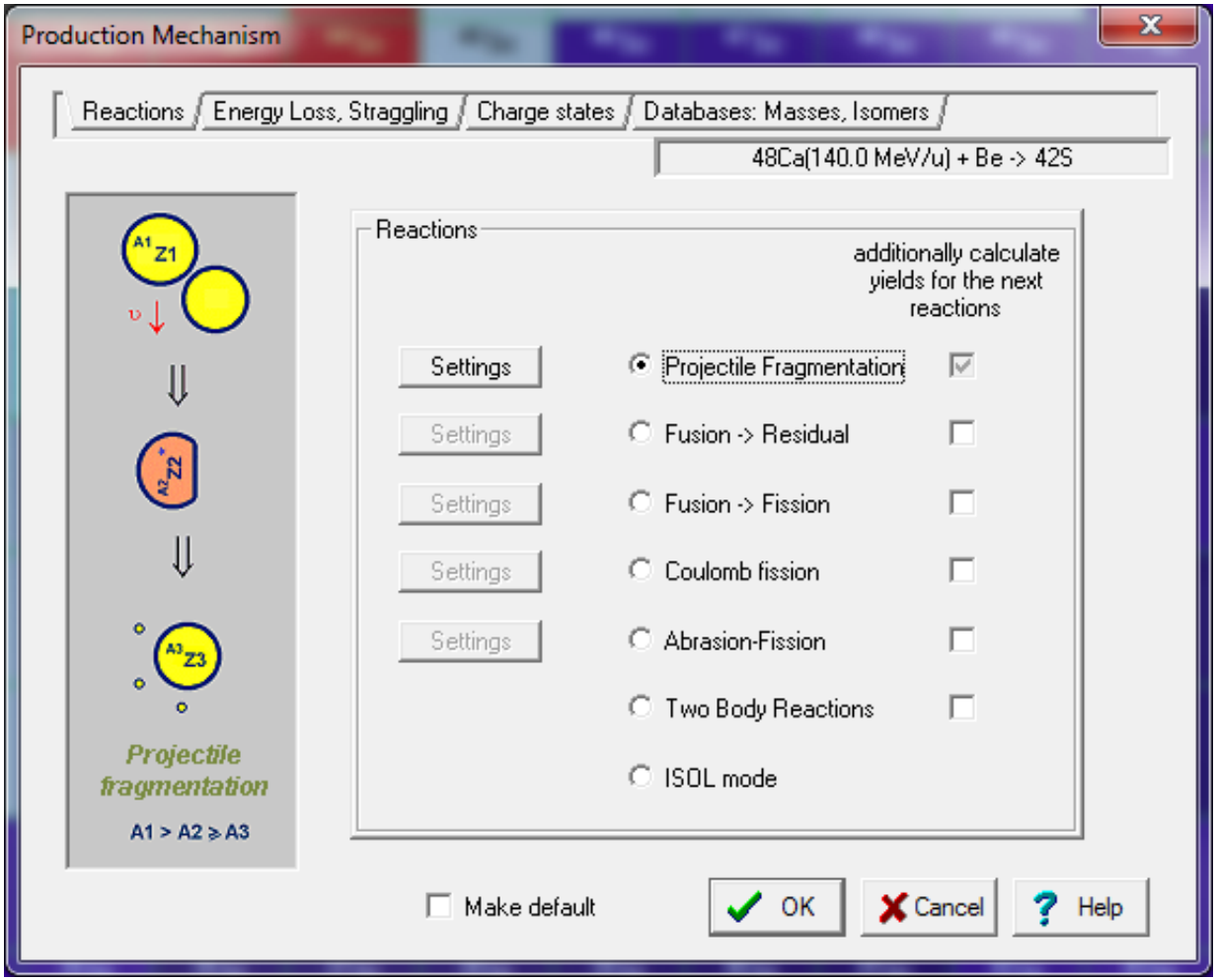
- The LISE^{++} program is designed
  - to predict intensities and purities for the planning of future experiments with in-flight separators
  - is also essential for radioactive beam tuning where its results can be quickly compared to on-line data.





Reaction Mechanisms

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



Fragment Separator Construction

- 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.

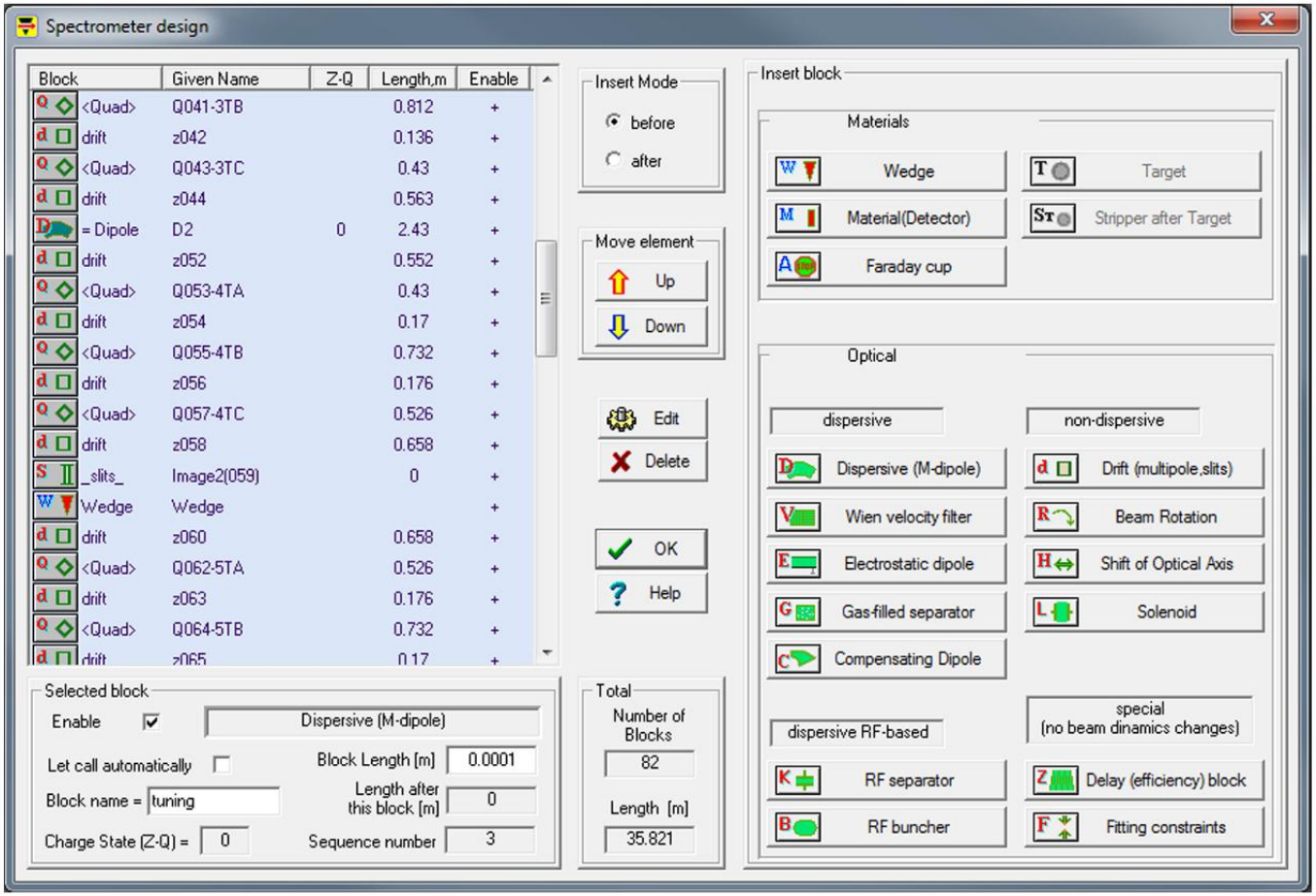
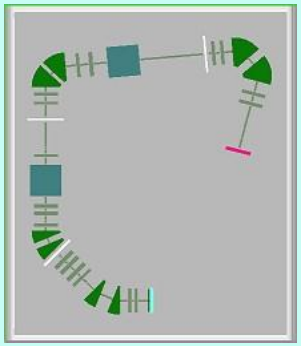


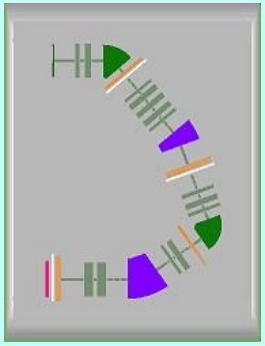
Fig. 1. Updated view of the "Spectrometer Design" dialog window.

Application

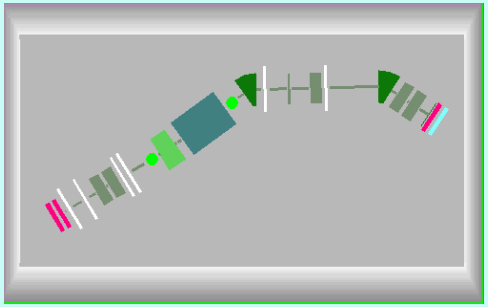
Includes *extended* configurations of separators at NSCL/MSU, RIKEN, GANIL, GSI, FLNR/JINR, TAMU, TRIUMF, ANL and others.



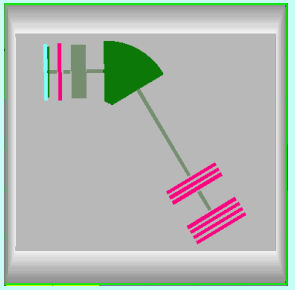
SECAR, *MSU*



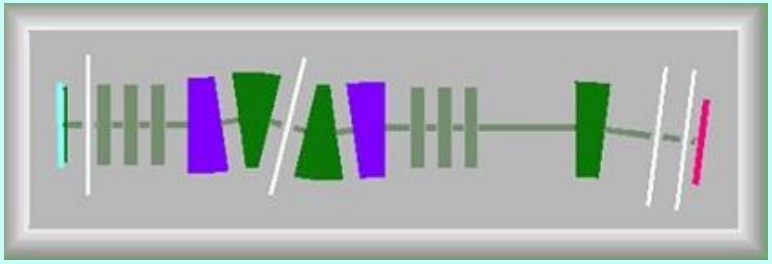
DRAGON, *Canada*



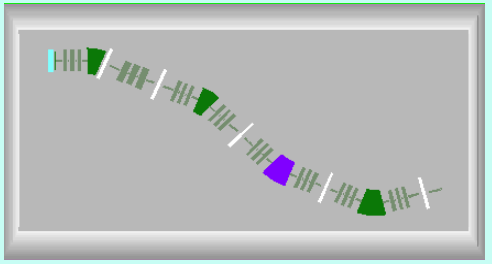
MARS, *TAMU*



PRISMA, *Italy*

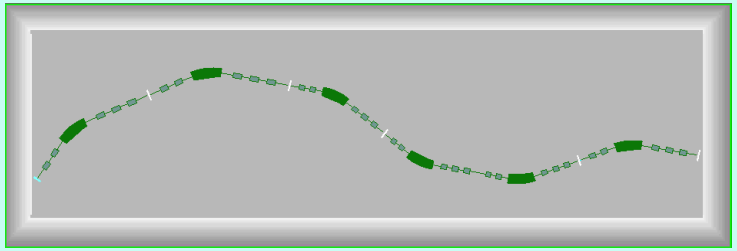


SHELS, *Russia*



S^3, *France*

BigRIPS+ZeroDegree, *Japan*



SuperFRS_HEB, *Germany*

LISE^{++} package

- The code is distributed free with the LISE^{++} user license
- Official site : lise.nscl.msu.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^{++} 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 optic
- «ETACHA4» (charge-state distribution code) *(new)*,
- «Global» (charge-state distribution code),
- «Charge» (charge-state distribution code),
- «Spectroscopic Calculator" (of J.Kantele»)

LISE^{++} 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

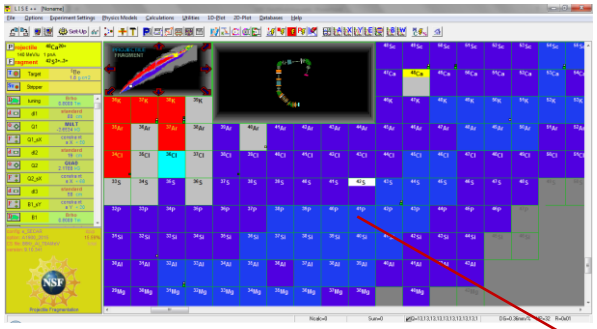
Databases:

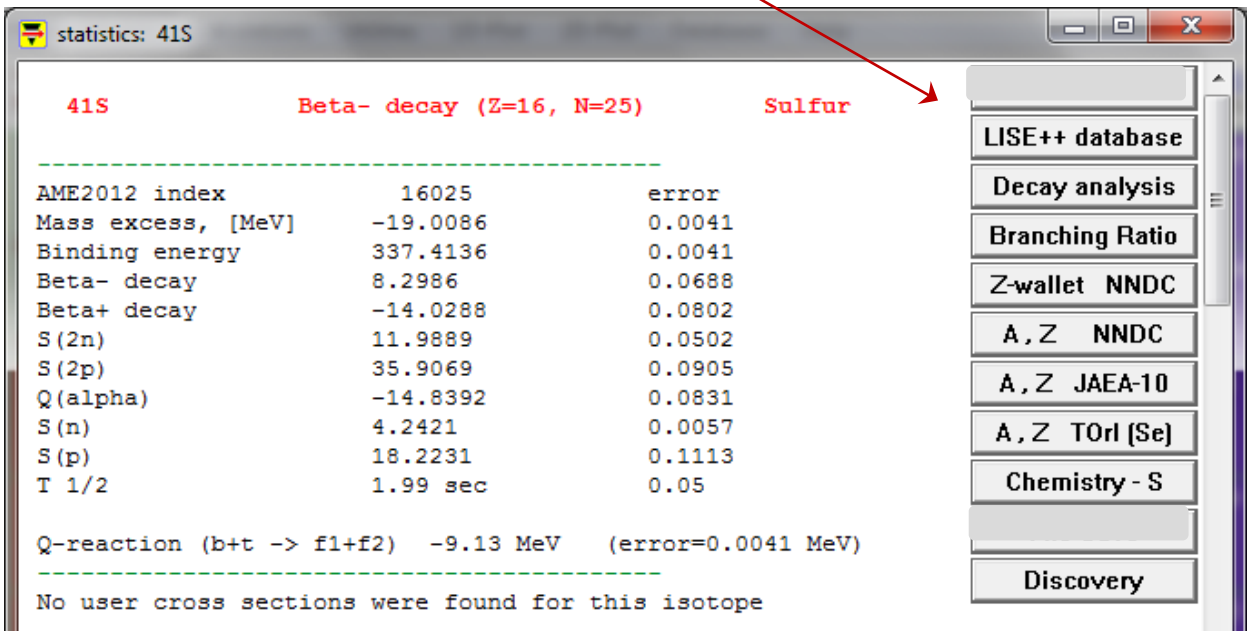
- Nuclide and Isomeric State databases with utilities,
- Large Set of Calculated Mass Tables (includes FRIB mass tables),
- Ionization Energy database (used with the Ion Mass calculator),
- Decay Branching Ratio database (used with the Radiation Residue calculator),

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.

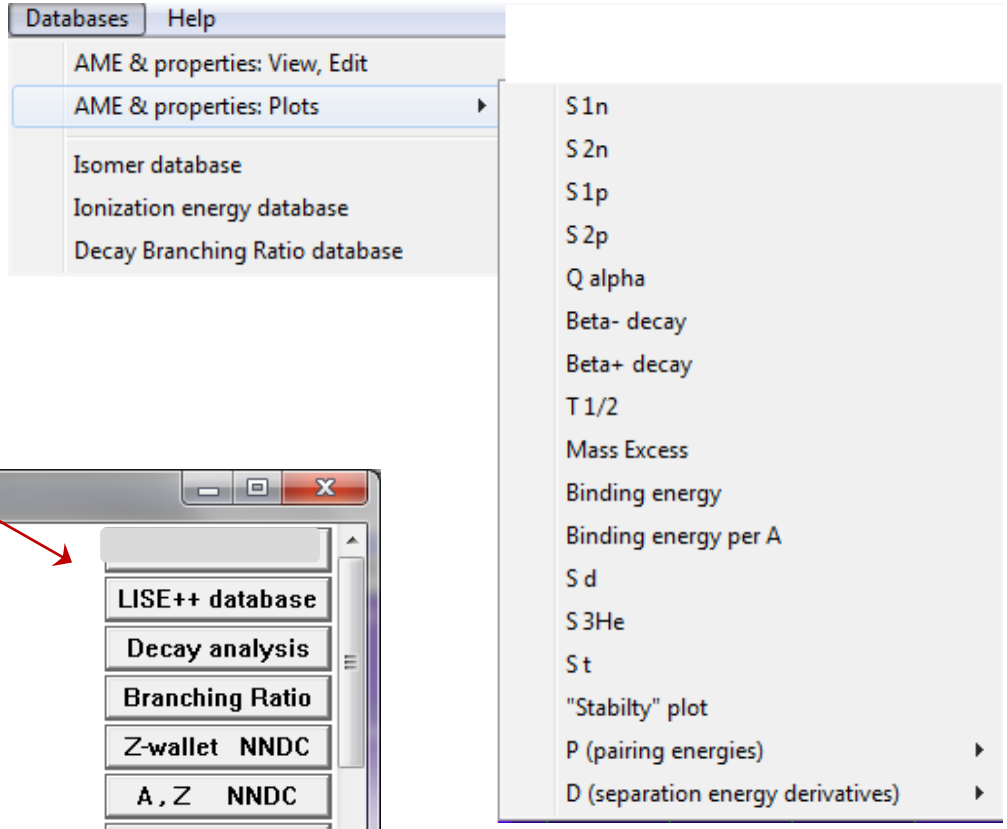
Access to internal and external databases

Throw the Table of nuclides





Throw the Menu



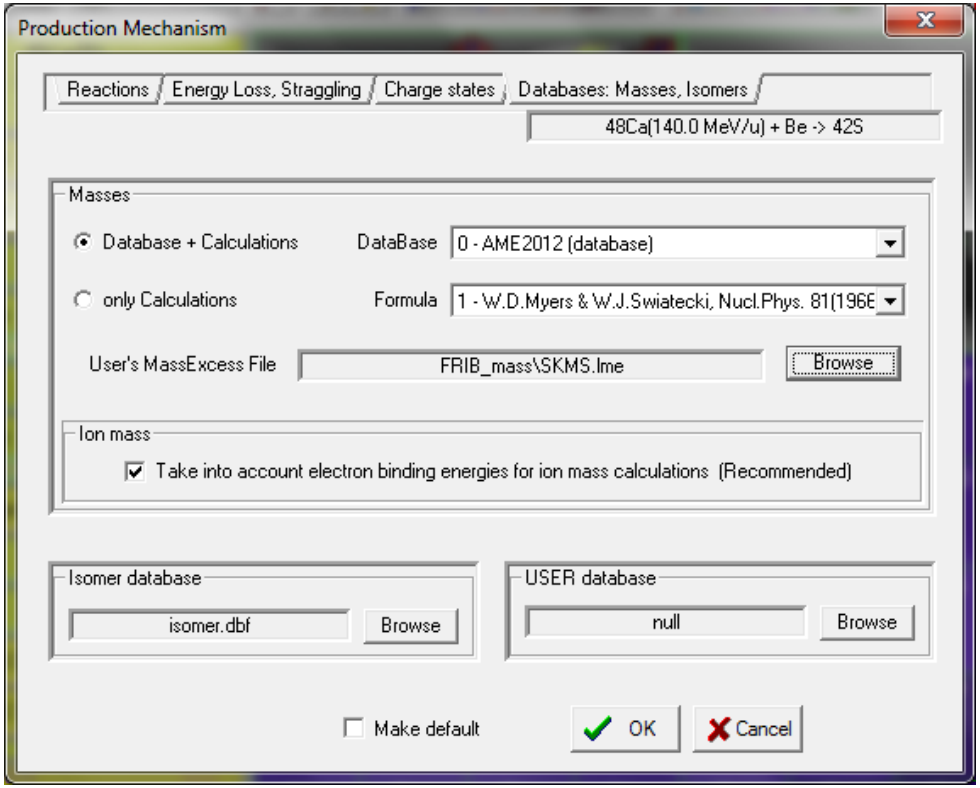
Databases used (produced) in (with) LISE^{++}

- 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/ 😐

Masses

- 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 ?

Ionization energy database & Ion mass calculator

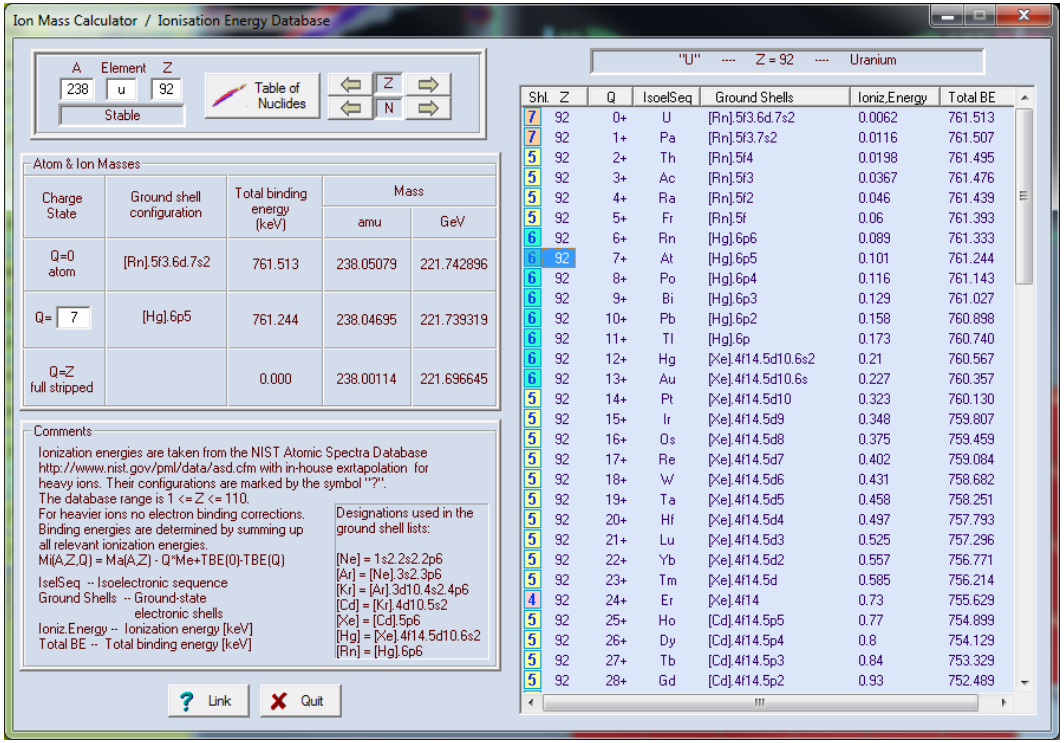
- Ion mass for E-M device precise settings and isotope selection
- Generation of X-ray spectra (in future with ETACHA4)

using

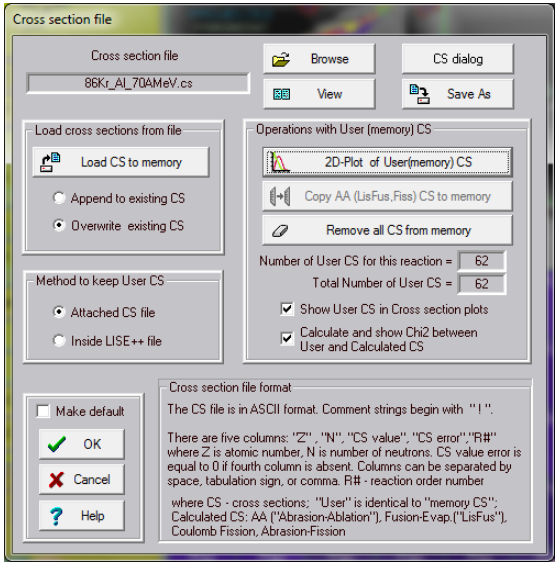
- AME2012 (or other Mass model)
- Ionization Energy Database (NIST Atomic Spectra Database Ionization Energies)

$^{238}U^{92+}$ ion mass

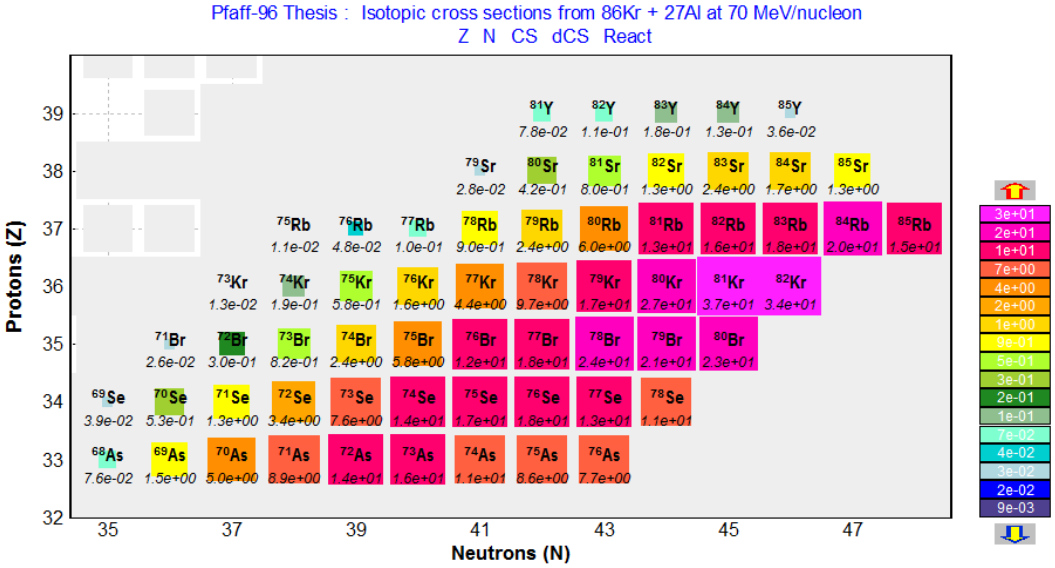
• v.9.8.114	atomic mass was used	238.0508 amu
• v.9.8.117	correction for e- masses	238.0003 amu
• v.9.10.131	correction for e- binding energies	238.0011 amu



Experimental Production Cross Sections



Cross-sections



LISE++ built-in cross section files

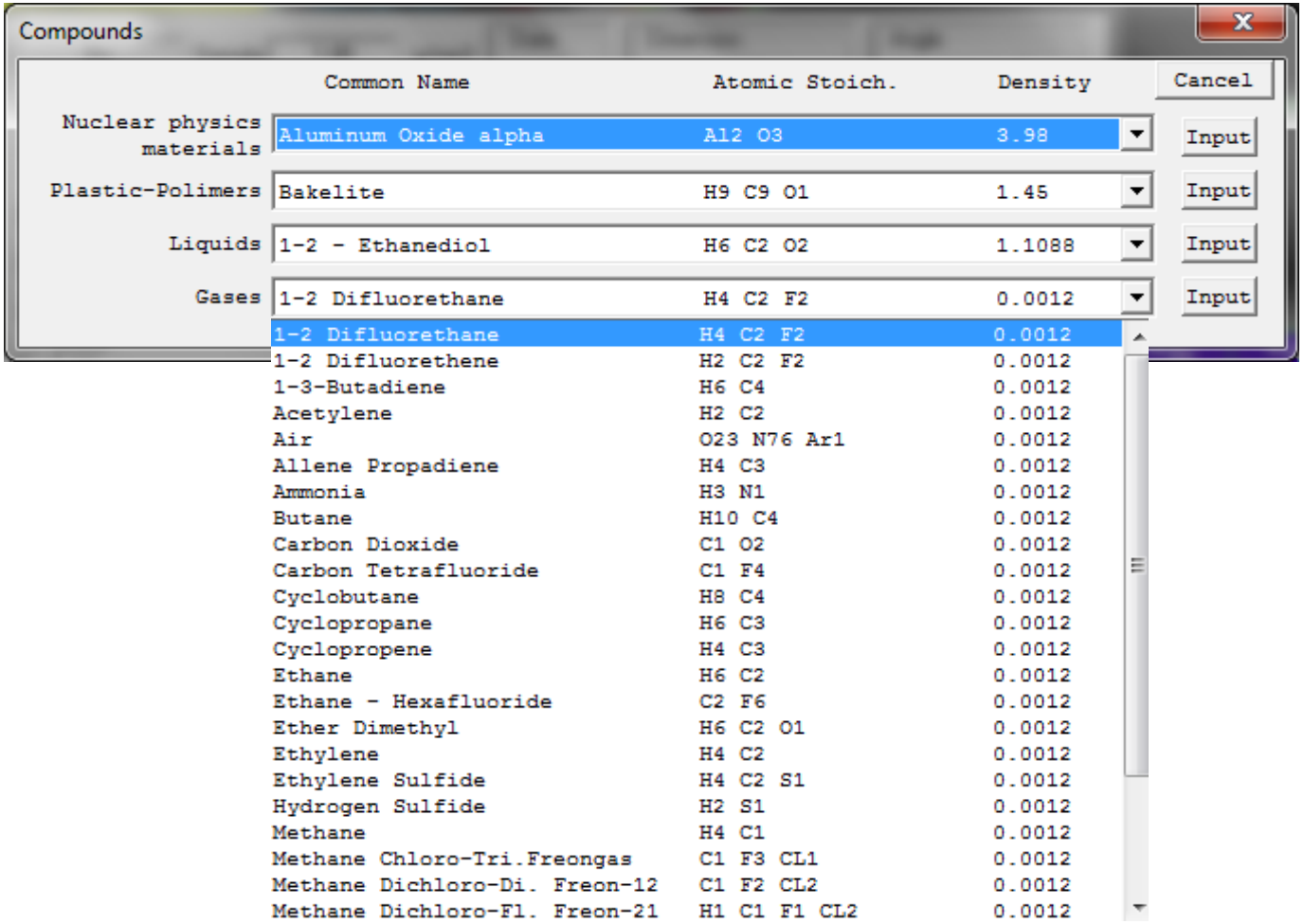
```
\129Xe_Al_790AMeV.cs
\136Xe_Al_760AMeV.cs
\208Pb\208Pb_1H_1AGeV_evap.cs
\208Pb\208Pb_1H_1AGeV_fission.cs
\208Pb\208Pb_2H_1AGeV_evap.cs
\208Pb\208Pb_2H_1AGeV_fission.cs
\238U\238U_Be_750AMeV_fission.cs
\238U\238U_d_1AGeV_fission.cs
\238U\238U_d_1AGeV_fragmentation.cs
\238U\238U_p_1AGeV_fission.cs
\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_Al_70AMeV.cs
```

+ user can enter his own data

- Need more! (installer size?)
- External link?
- Data format

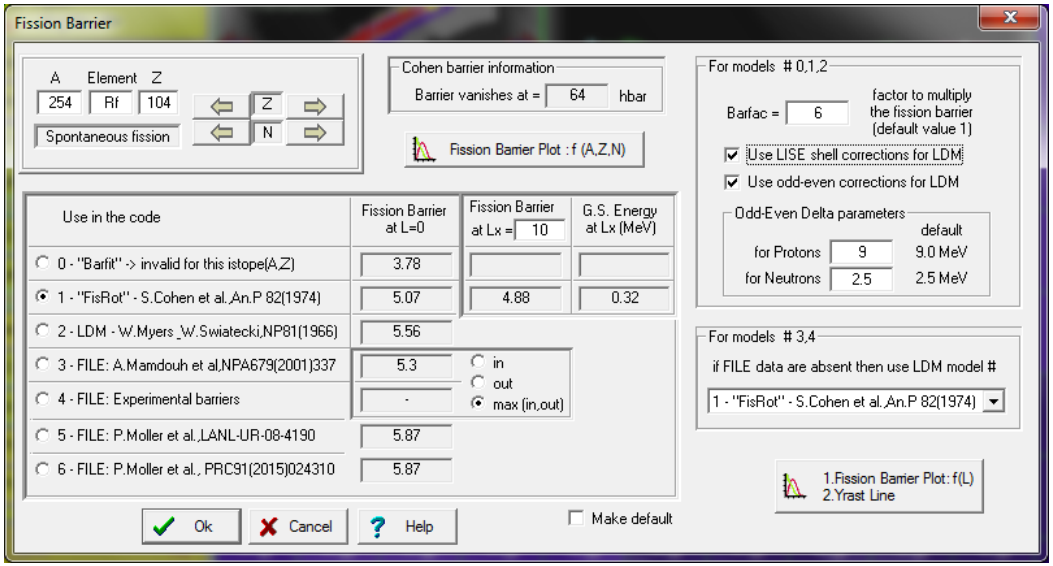
Compound database

A lot of complains…



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

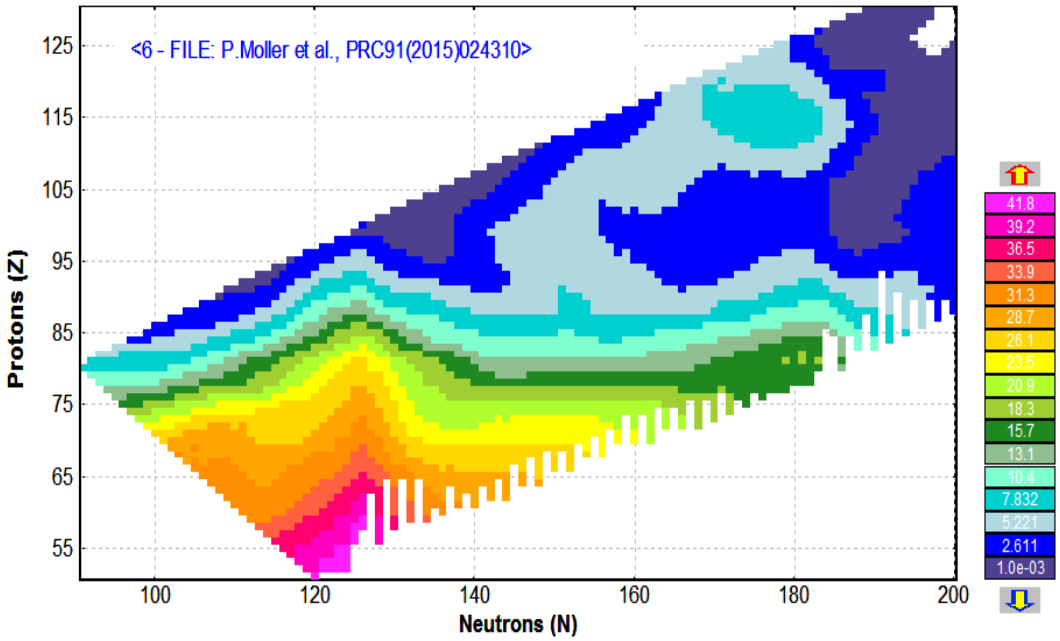
Fission barriers

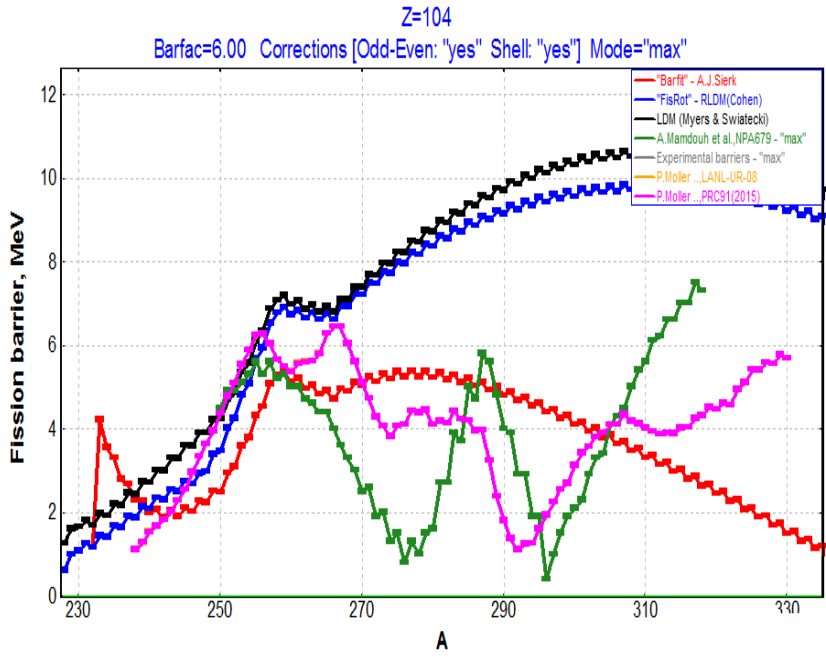


See Walter's talk

SHE vs. barriers

Fission barrier





Isomeric states database ($10^{-7} \div 10^{-3}$ sec)

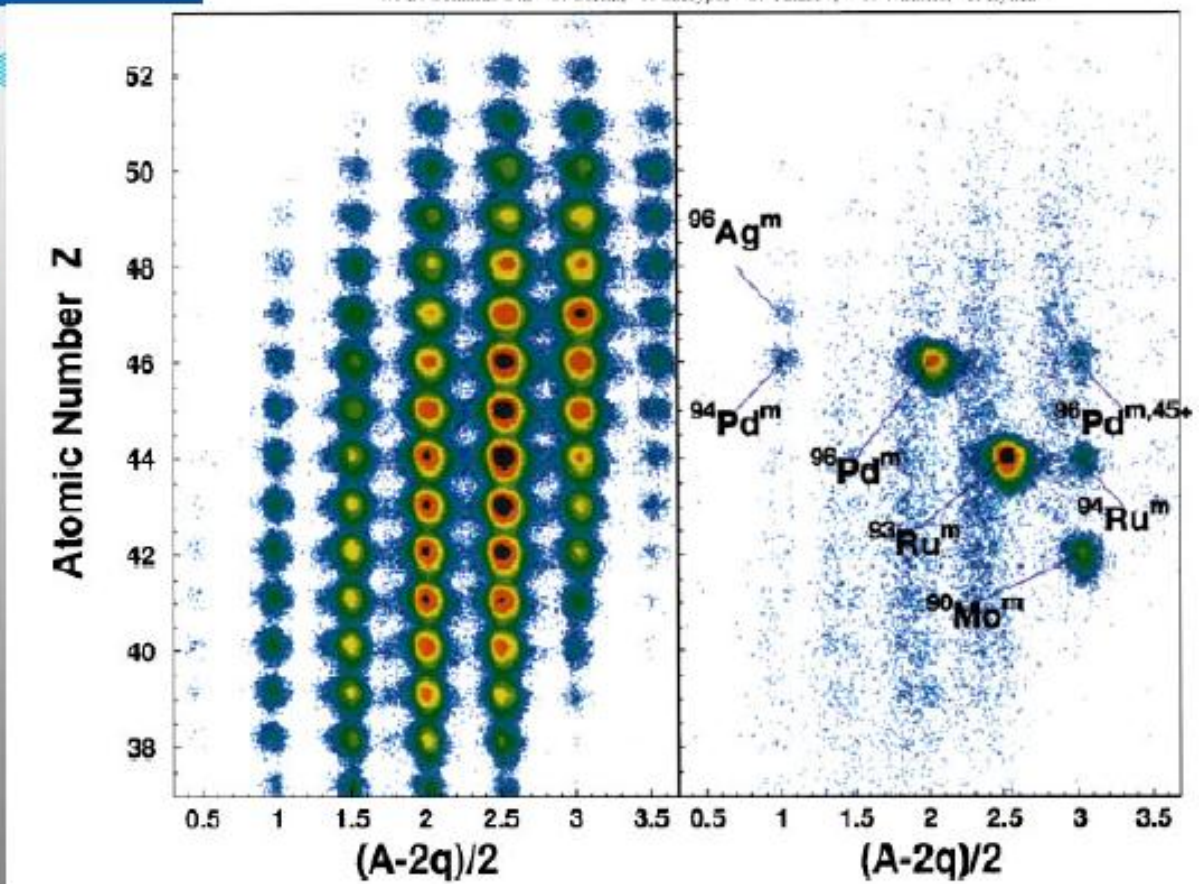
It will be nice to simulate…

LISE++
γ–database

γ–registration settings

New μs isomers in $T_z=1$ nuclei produced in the ^{112}Sn(63.4 MeV)+^{nat}Ni reaction

R. Grzywacz,[1,2] R. Anne,[2] G. Auger,[2] C. Borcea,[3] J. M. Corre,[2] T. Dörfler,[4] A. Fomichov,[5] S. Grevy,[6] H. Grawe,[7] D. Guillemaud-Mueller,[1] M. Huyse,[8] Z. Janas,[7] H. Keller,[7] M. Lewitowicz,[2] 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,[1,10] M.G. Saint-Laurent,[2] W. D. Schmidt-Ott,[4] O. Sorlin,[6] J. Szerypo,[1] O. Tarasov,[5,2] J. Wauters,[8] J. Zylicz[1]



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

μs Isomeric states - powerful particle identification tool

LISE^{++} simulations

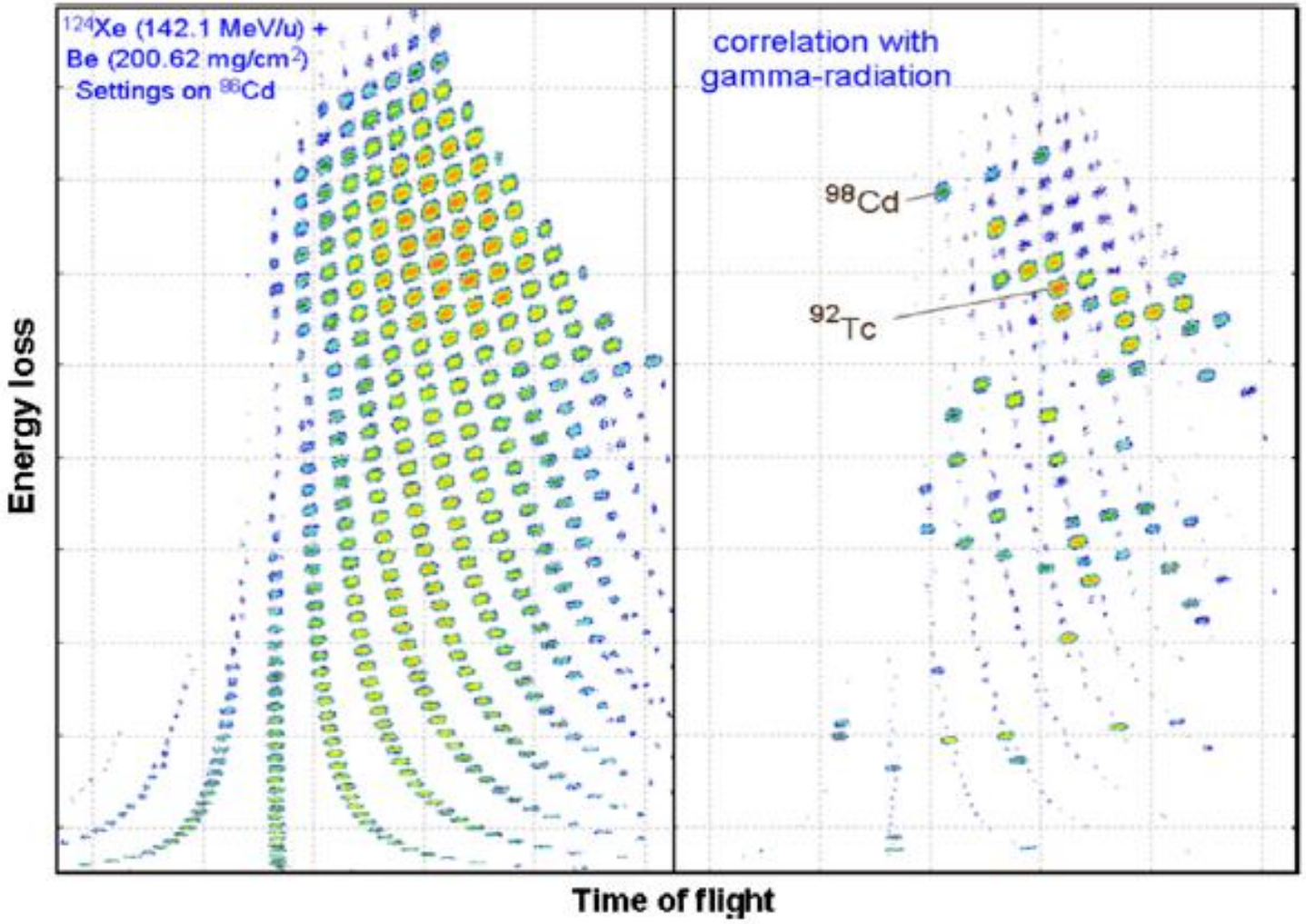
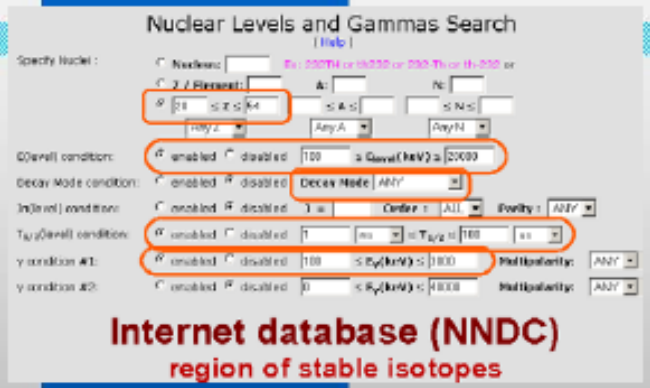
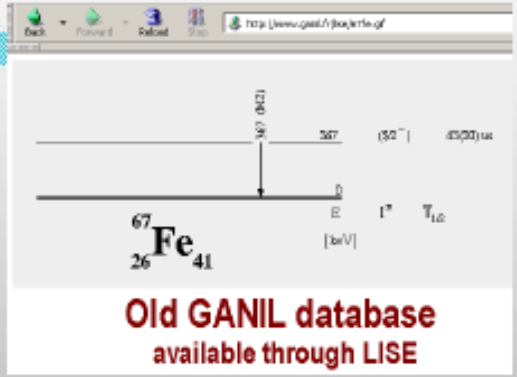
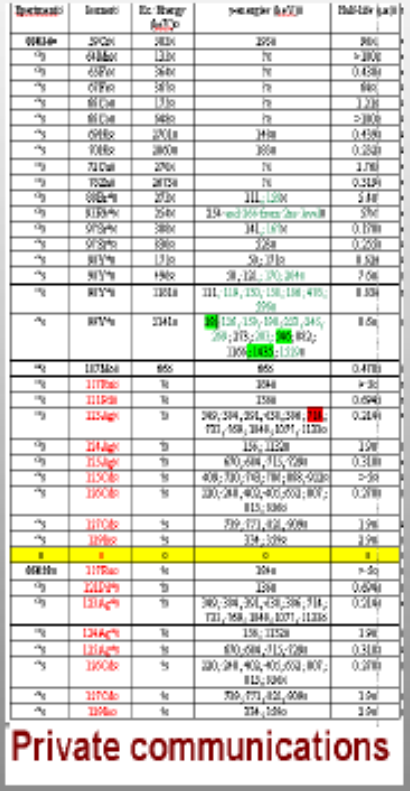


Fig. 2. LISE++ identification plot of all nuclei produced in the reaction ^{124}Xe + Be (left panel) and those in coincidence with gamma-radiation (right panel) simulated by analogy to the work of [24] with a ^{112}Sn beam.

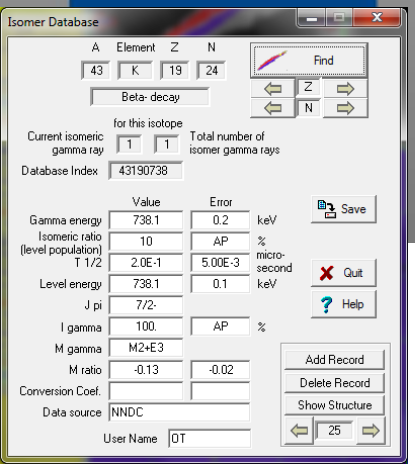
LISE isomer database







LISE++ database (dbf-format)



New experimental data

- The database should be updated!
- Think about new database format and corresponding tools (search, edit, plot, import)
- Non-convenient import format

Decay branching ratio database in LISE^{++}

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

Nuclear Data Sheets 128 (2015) 131–184

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

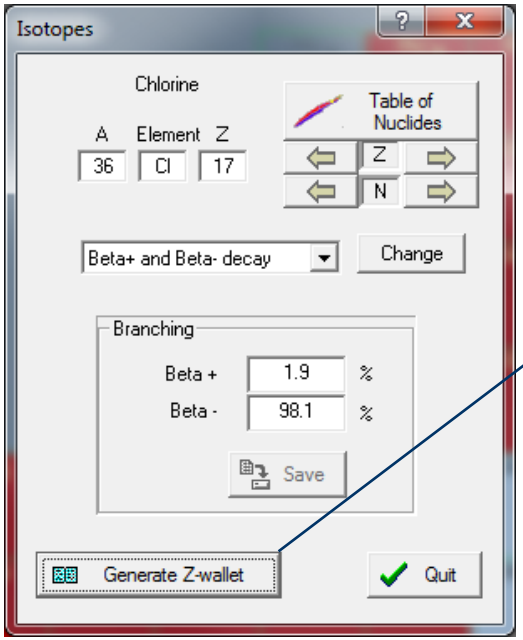
M. Birch,[1] B. Singh,[1,*] I. Dillmann,[2] D. Abriola,[3] T.D. Johnson,[4] E.A. McCutchan,[4] and A.A. Sonzogni[4]

[1] *Department of Physics and Astronomy, McMaster University, Hamilton, Ontario L8S 4M1, Canada*
[2] *TRIUMF, Vancouver, British Columbia V6T 2A3, Canada*
[3] *Department of Physics, TANDAR Laboratory, C.N.E.A., Buenos Aires, Argentina*
[4] *National 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 $Z = 2 - 28$ (^{8}He – ^{80}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 $38 \le Z$ are taken from NNDC

Ratios for higher Z will be entered soon.



Decay Branching Ratio

Z=17 (Chlorine)

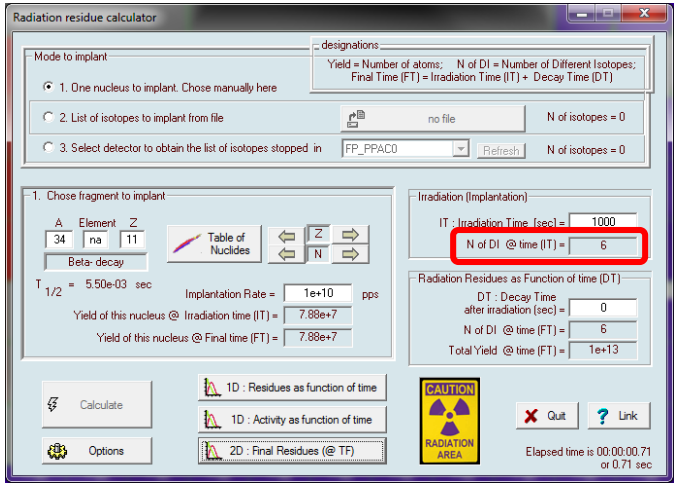
A	decay1	branch,%	decay2	branch,%	T 1/2, s	Abundance,%
30	Unknown	100			8.430e-13	
31	Beta +	100			1.500e-01	
32	Beta +	100			2.980e-01	
33	Beta +	100			2.511e+00	
34	Beta +	100			1.527e+00	
35	Stable	100				75.760
36	Beta +	1.90	Beta -	98.10	9.503e+12	
37	Stable	100				24.240
38	Beta -	100			2.234e+03	
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	

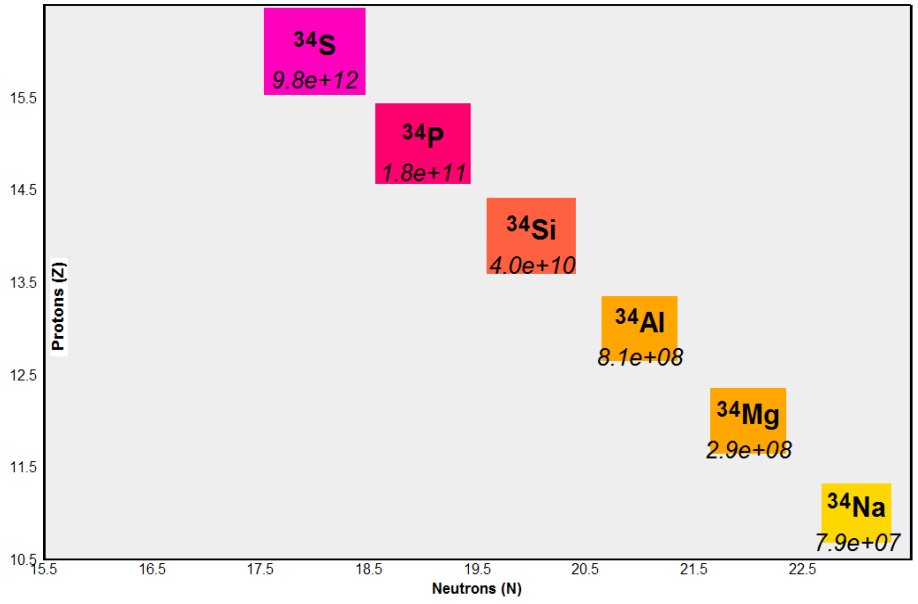
T 1/2 : compilation of experimental and calculated values.
See the AME dialog for details

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

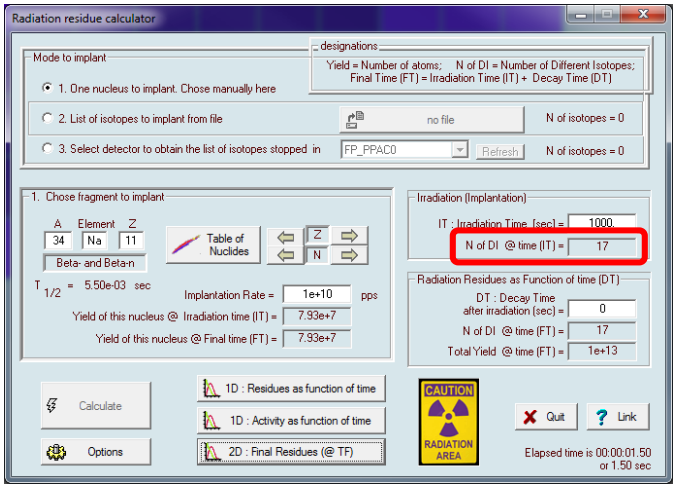
Decay branching ratio vs. Radiation Residue calculation

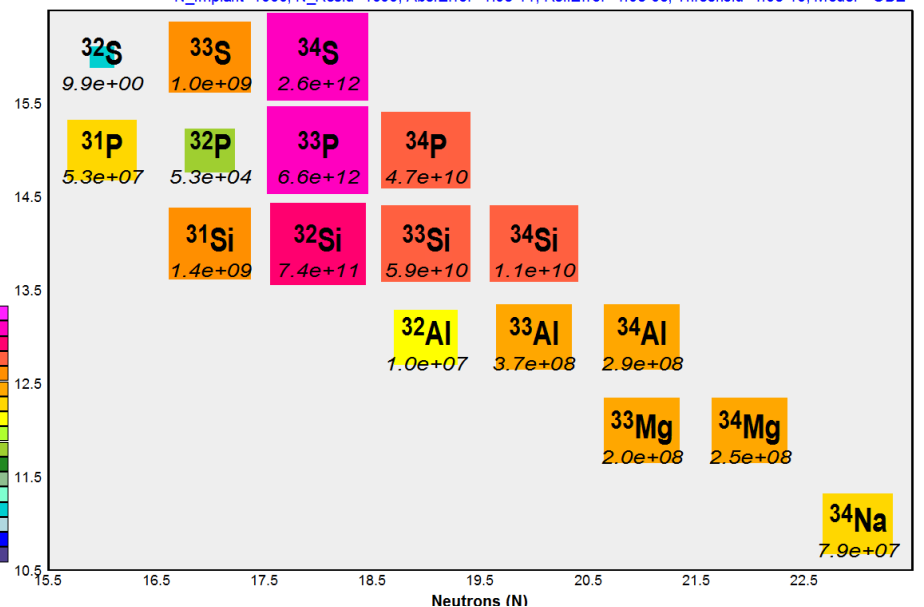
v.9.10.331. No Decay Branch Database



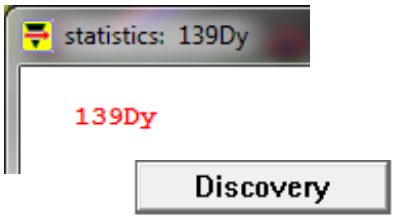


v.9.10.341. With Decay Branch Database





Link to the discovery database



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

^{139}Dy

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

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