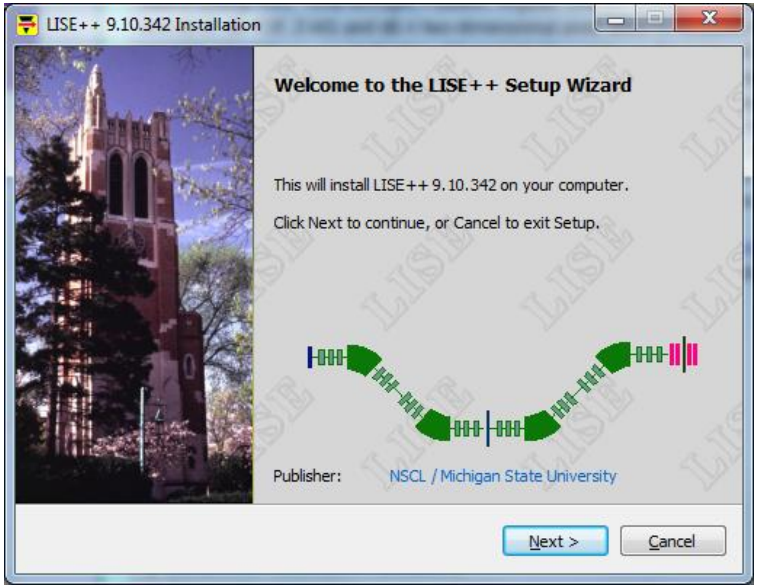
Predictions of Isotope Production Yields

by Oleg B. Tarasov (NSCL/MSU)

- Introduction to LISE^{++} code
- FRIB rates
- "Direct" production: ^{44}Ti example
- Commensal operation:
  Helium-Jet Ion-Guide System



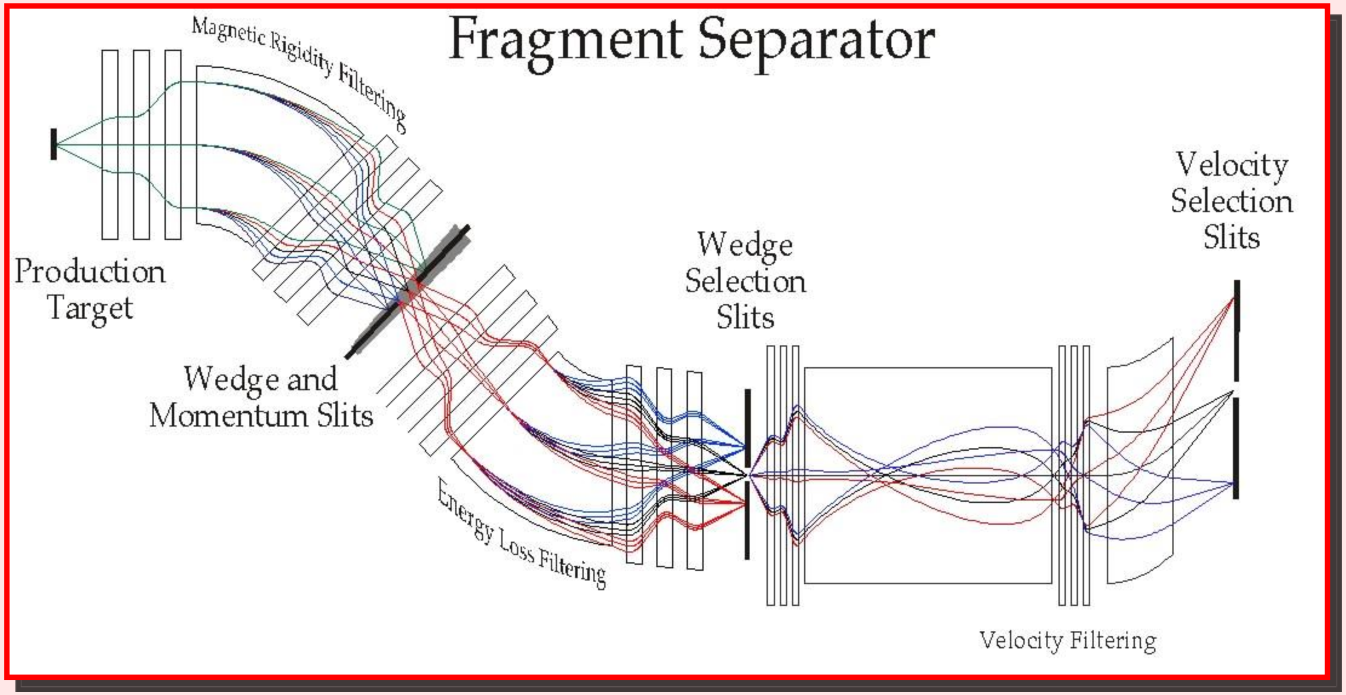
LISE^{++} : EXOTIC BEAM PRODUCTION WITH FRAGMENT SEPARATORS

Introduction

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

In-Flight isotope production: Basic principle of operation

1. Production



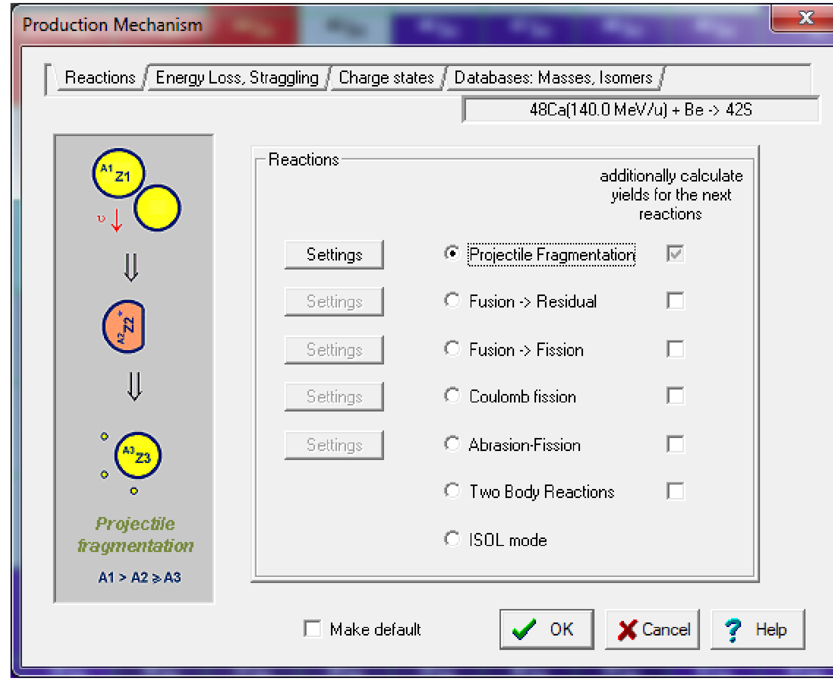
2. Separation

3. Registration, Identification

Production : Reaction Mechanisms

Table
Reactions and production models implemented in LISE++

Reaction	Production cross-section model	Ref.
Projectile fragmentation	EPAX 2.15, 3.1	[17]
	LISE++ abrasion–ablation	[27]
Fusion-residues	LisFus model	[27]
	PACE4 (manually)	[28]
Fusion–fission	LISE++ package	[29]
Coulomb fission	LISE++ package	[30]
Abrasion–fission	LISE++ 3EER model	[31]
Two body kinematics	EPAX 2.15 (temporary)	



References:

[17] K. Summerer, B. Blank, Phys. Rev. C 61 (2000) 034607; K. Summerer, Phys. Rev. C 86 (2012) 014601

[27] O. Tarasov, D. Bazin, Nucl. Instr. and Meth. B 204 (2003) 74.

[28] A. Gavron, Phys. Rev. C 21 (1980) 230.

[29] O.B. Tarasov, A.C.C. Villari, , Nucl. Instr. and Meth. B 266 (2008) 4670-4673.

[30] O.B. Tarasov, Eur. Phys. J. A 25 (2005) 751; Tech. Rep. MSUCL1299, NSCL, Michigan State University, 2005.

[31] O.B. Tarasov, Tech. Rep. MSUCL1300, NSCL, Michigan State University, 2005.

Electromagnetic separation devices in LISE^{++}

Separation device	Changeable field	Strength	Selection by
Magnetic dipole	Magnetic (B[T])	$\vec{F}_B = q\vec{v} \times \vec{B}$	Magnetic rigidity $B\rho = \frac{mv}{q}$ [T·m]
Gas-filled separator	Magnetic (B[T])	$\vec{F}_B$	Magnetic rigidity
Solenoid	Magnetic (B[T])	$\vec{F}_B$	Focusing (combination A,q,v)
Electrostatic dipole	Electric (E [kV/m])	$\vec{F}_E = q\vec{E}$	Electric rigidity $E\rho = \frac{mv^2}{q}$ [J/C]
RF kicker	Electric (E [kV/m])	$\vec{F}_E$	Time
RF buncher	Electric (E [kV/m])	$\vec{F}_E$	Bunching
Wien-filter *E-cross-B filter*	Magnetic (B[T]) Electric (E [kV/m])	$\vec{F} = \vec{F}_B + \vec{F}_E$	Velocity

- “Wedge” selection
- Decay time selection

Fragment Separator Construction

- with <u>different sections called "blocks"</u> (magnetic and electric multipoles, solenoid, velocity filter, RF deflector and buncher, material in beam, drift, rotation element, and others).

- a <u>user-friendly interface</u> that helps to seamlessly construct a fragment separator from the different blocks.

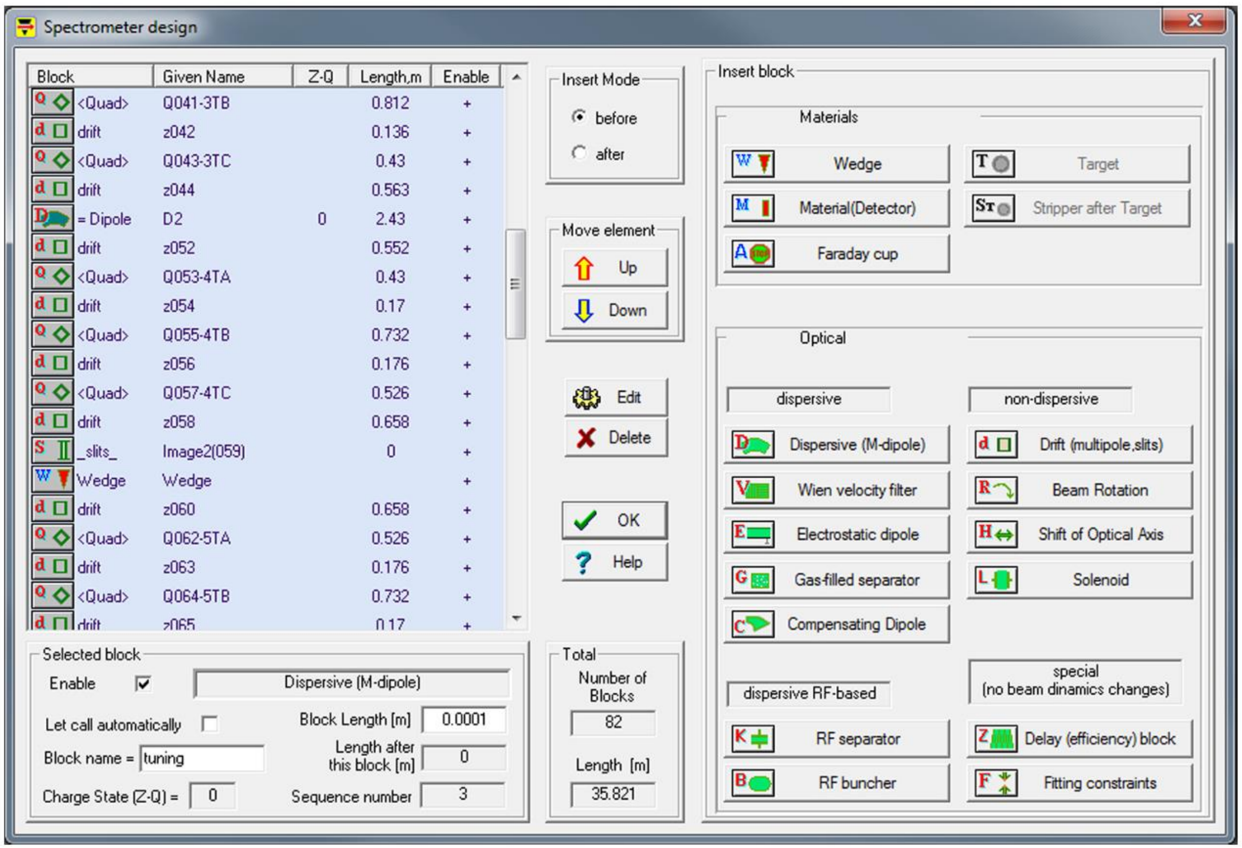
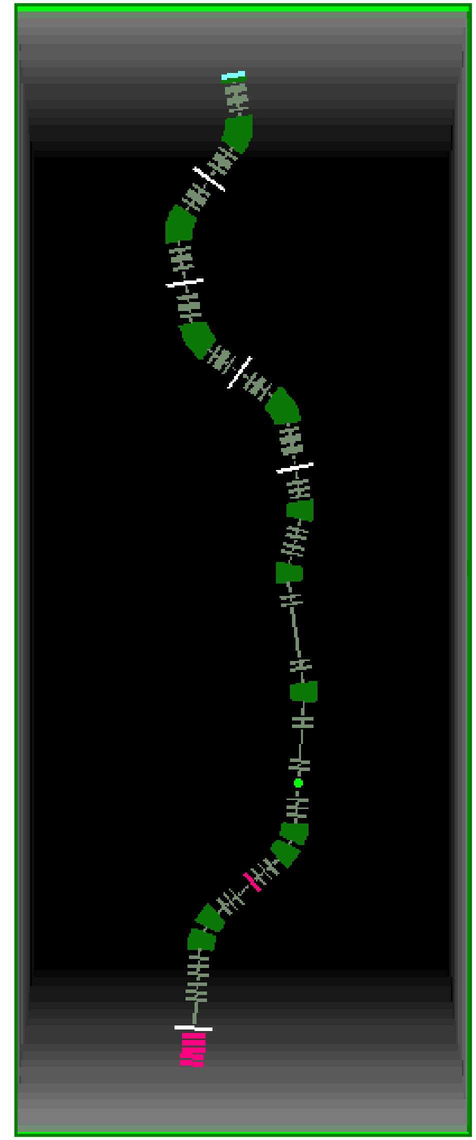


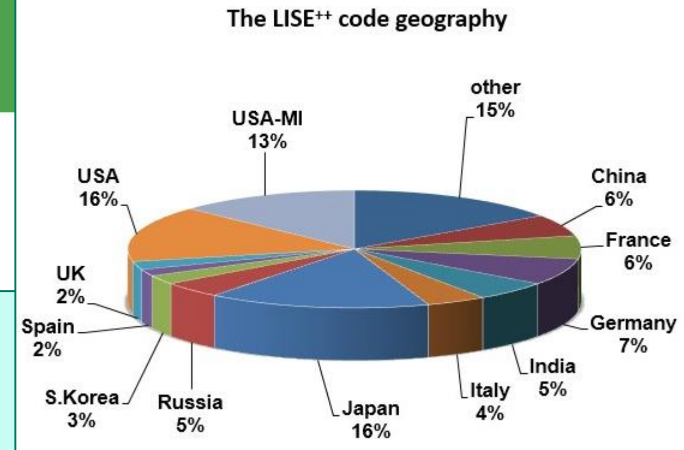
Fig. 1. Updated view of the "Spectrometer Design" dialog window.

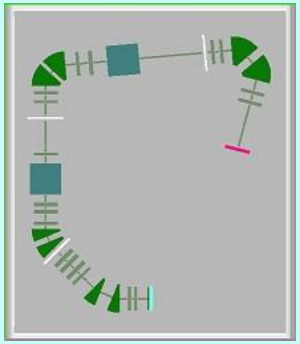


Configuration: A1900_S800BL (2nd order) 164 blocks

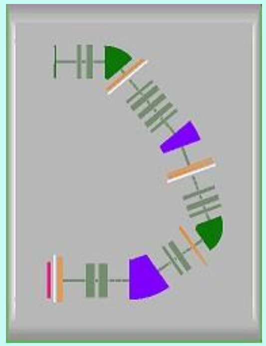
Application

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

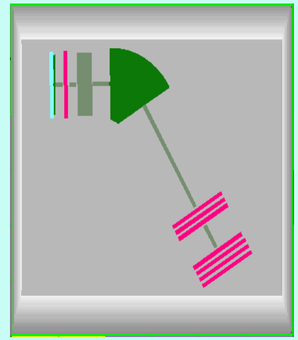




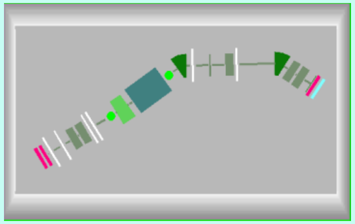
SECAR, *MSU*



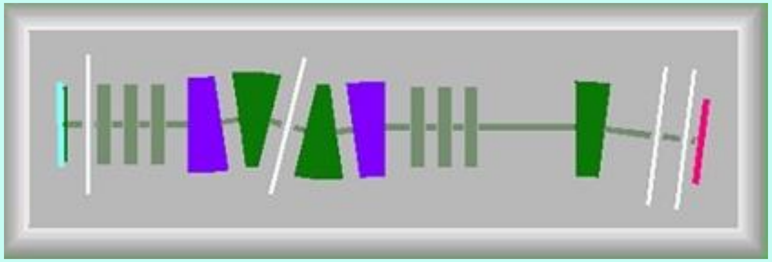
DRAGON, *Canada*



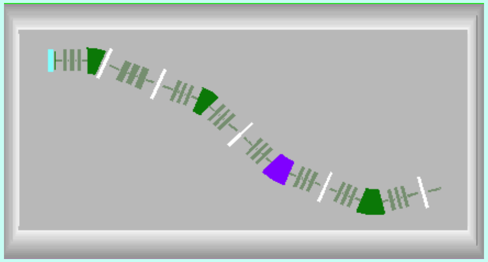
PRISMA, *Italy*



MARS, *TAMU*

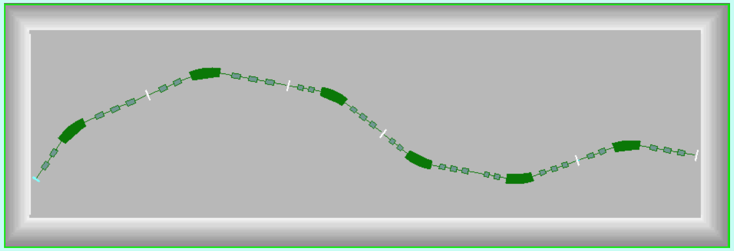


SHELS, *Russia*



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 9.10.343, 15-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:

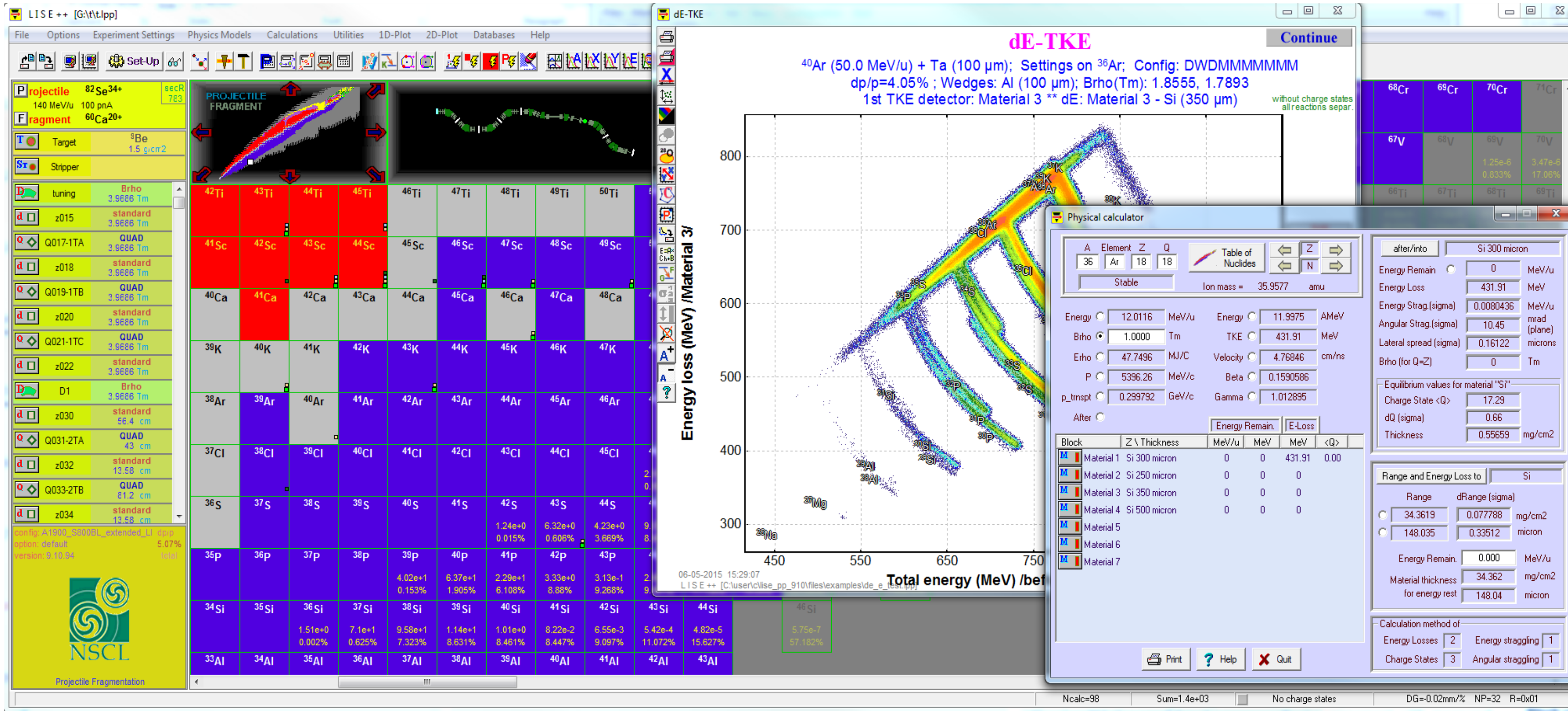
- **Stripper Foil Lifetime Utility,**
- **Brho Analyzer,**
- **Twinsol (solenoid) utility,**
- **Units Converter,**
- **ISOL Catcher,**
- **Decay Analysis** (includes Proton, Alpha, Cluster, Sp.Fission half-lives calculation),
- **Reaction Utilities** (Characteristics, Converters, Plots),
- **«BI»-**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

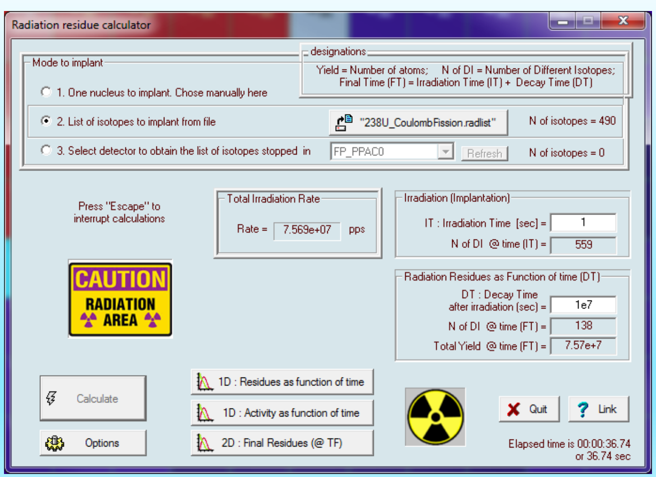
Databases:

- **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.

LISE++ framework





New utility from 08/01/16

"Radiation Residue Calculator"

is important tool regarding to isotope harvesting

http://lise.nscl.msu.edu/9_10/RadiationResidue.pdf

FRIB: Beams and Rates

Site: https://groups.nscl.msu.edu/frib/rates/fribrates.html

https://groups.nscl.msu.edu/frib/rates/fribrates.html

Enter values for A and Z

A	44	
Z	22	
N	22	
	Ti	
$T_{1/2}$	1.890e+9	sec
	Calculate Yield	

Beam

AZ	58Ni	
Energy	275.3	MeV/u

Fragment

Energy	223.9	MeV/u
B_ρ (Q=Z)	4.560	Tm
Fast beam rate	1.46e+10	pps
Stopped beam rate	1.17e+8	pps
Reaccelerated beam rate	3.28e+7	pps

FRIB

FRIB Estimated Rates Version 1.06

02/07/2011

A). The LISE++ code (v.9.2.68) has been used for transmission calculations.
B). The rates are estimated based on the EPAX 2.15[1] cross section parameterization for fragmentation and the LISE++ 3EER model[2,3] for in-flight fission.
C). Reaccelerated and stopped beam rates above 1E+9 are very uncertain. The use of solid catchers may yield higher rates in some cases.
D). Estimated rates may change as the various assumptions are tested and refined.

[1] - K. Sümmerer and B. Blank, Phys. Rev. C 61 (2000) 034607.
[2] - O.B.Tarasov and D.Bazin, NIM B 266 (2008) 4657-466.
[3] - O.B. Tarasov, "LISE++ development: Abrasion-Fission", Tech.Rep. MSUCL1300, NSCL, Michigan State University 2005.

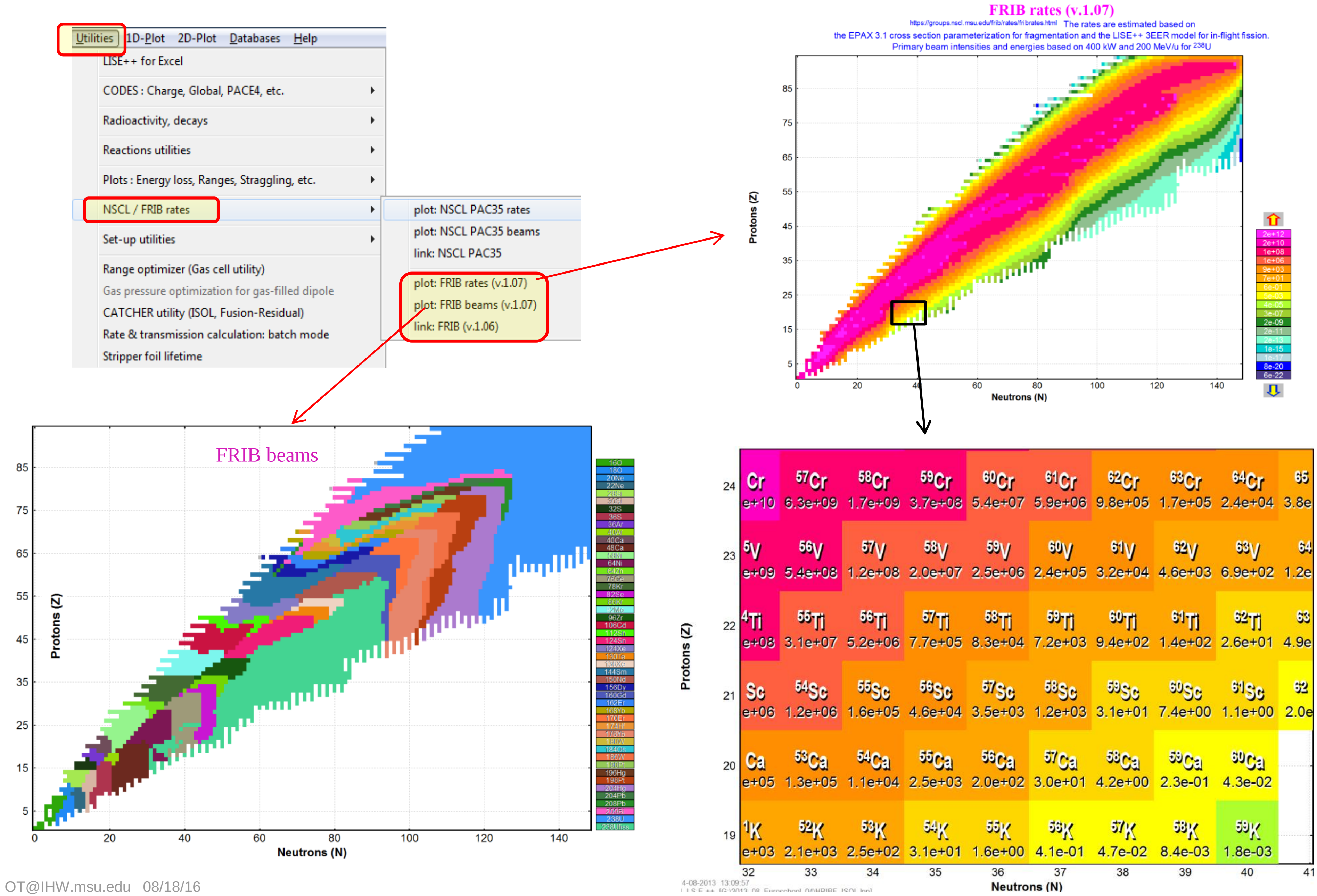
For further information regarding these calculations, please refer to the readme file (PDF - 420 kB).

Applet created by Dennis Wey.

Please contact Oleg Tarasov
with any questions or comments concerning to yields or this site.

FRIB: Beams and Rates

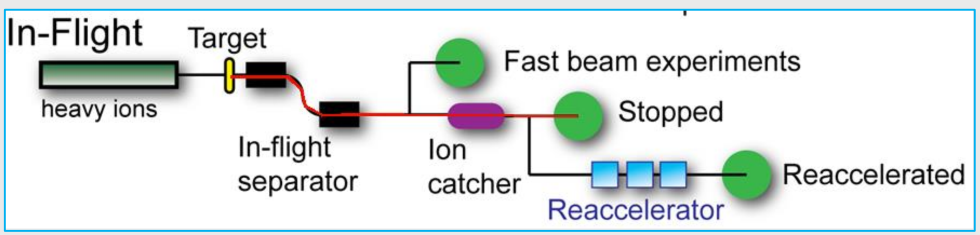
LISE++



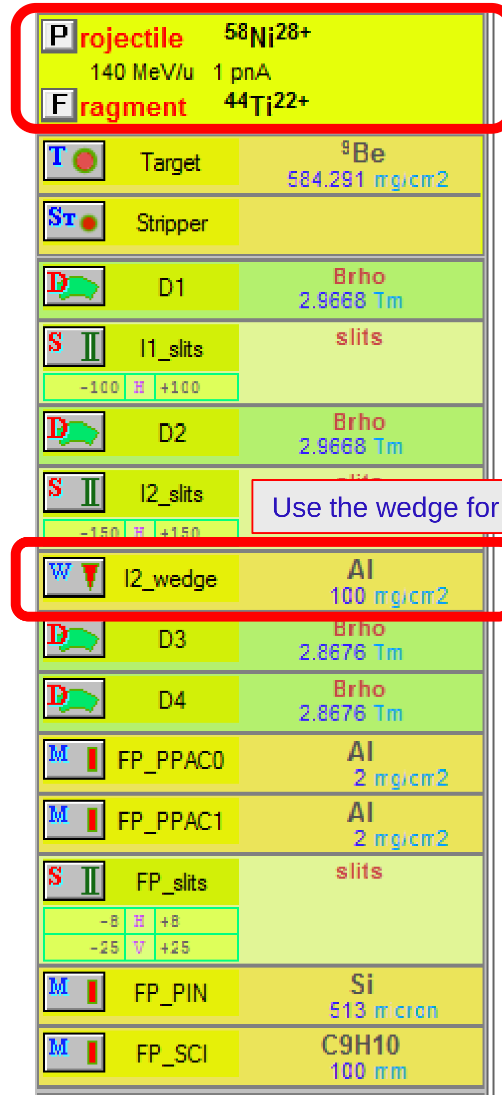
“Direct” production: ^{44}Ti example

Table 1. Priority isotopes for harvesting at FRIB. These isotopes were identified at t
Working Group meeting in Santa Fe, NM September 30 – October 1, 2010.

Isotope	Half-life	Application
^{32}Si	160 y	Tracer; geology and botany
^{44}Ti	60 y	Medicine, astrophysics, nuclear structure
^{48}V	16 d	Stockpile Stewardship
^{67}Cu	2.6 d	Medicine
^{85}Kr	10.0 d	Astrophysics, stockpile stewardship
Eu*		Stockpile Stewardship
^{211}Rn	14.6 h	Medicine
^{225}Ra	14.9d	Medicine, Electric Dipole Moment
^{225}Ac	10.0 d	Medicine



settings

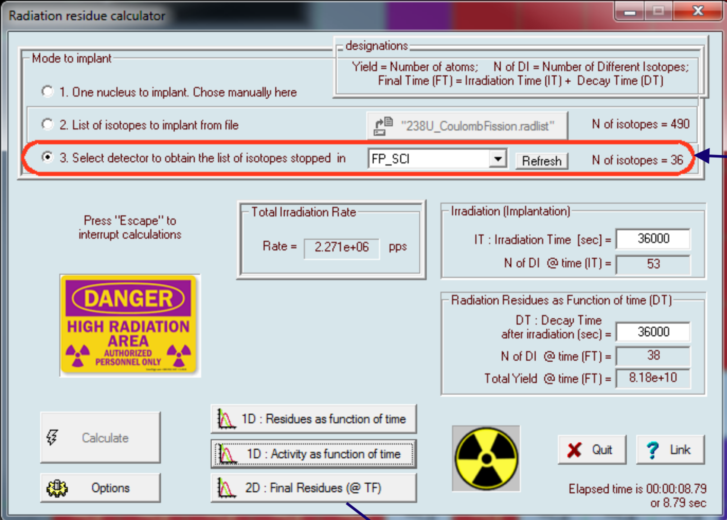


Use the wedge for purity

http://lise.nscl.msu.edu/9_10/radiation/RadiationResidue_44Ti.pdf

^{44}Ti's case : Residues

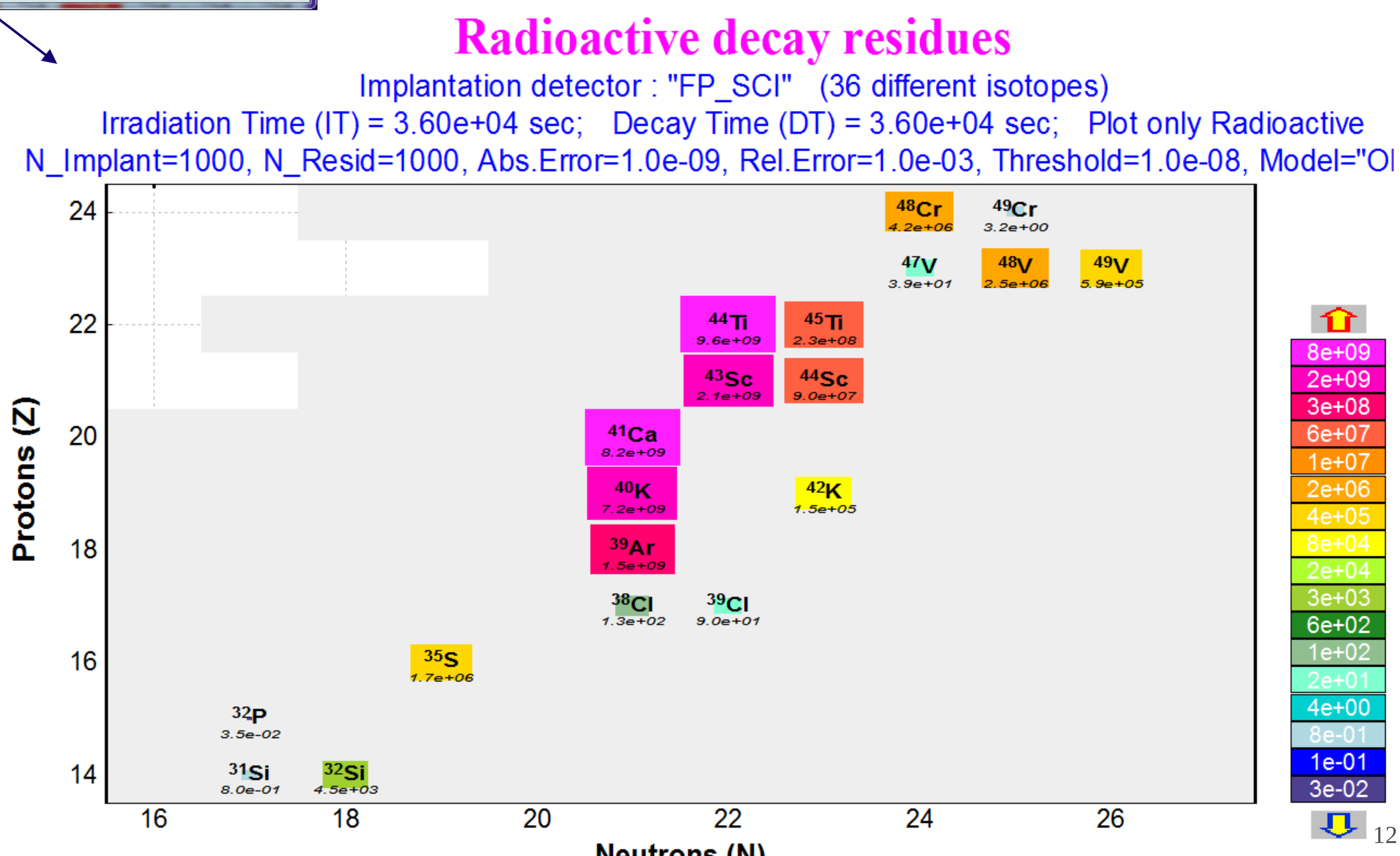
MICHIGAN STATE UNIVERSITY
LISE++



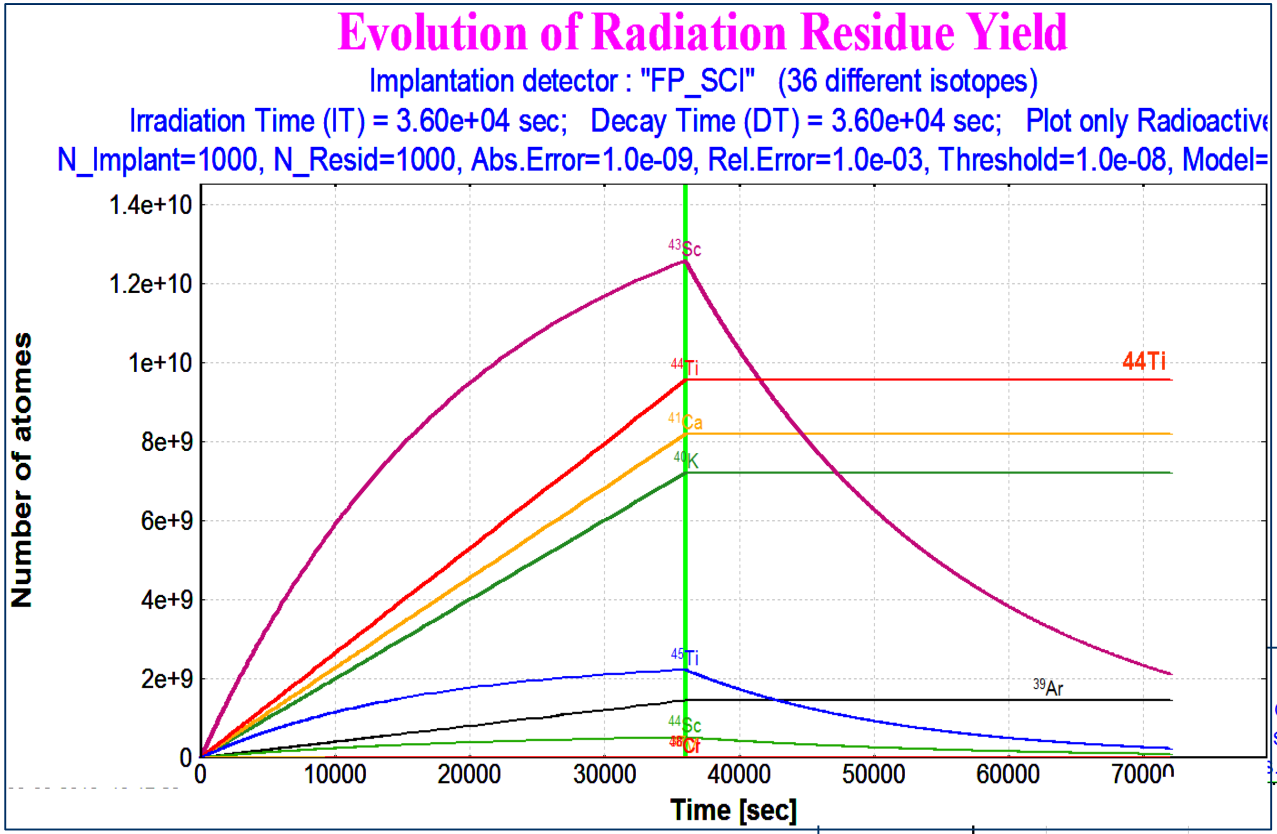
Isotopes selected by the Fragment-Separator are implanted in FP_SCI detector

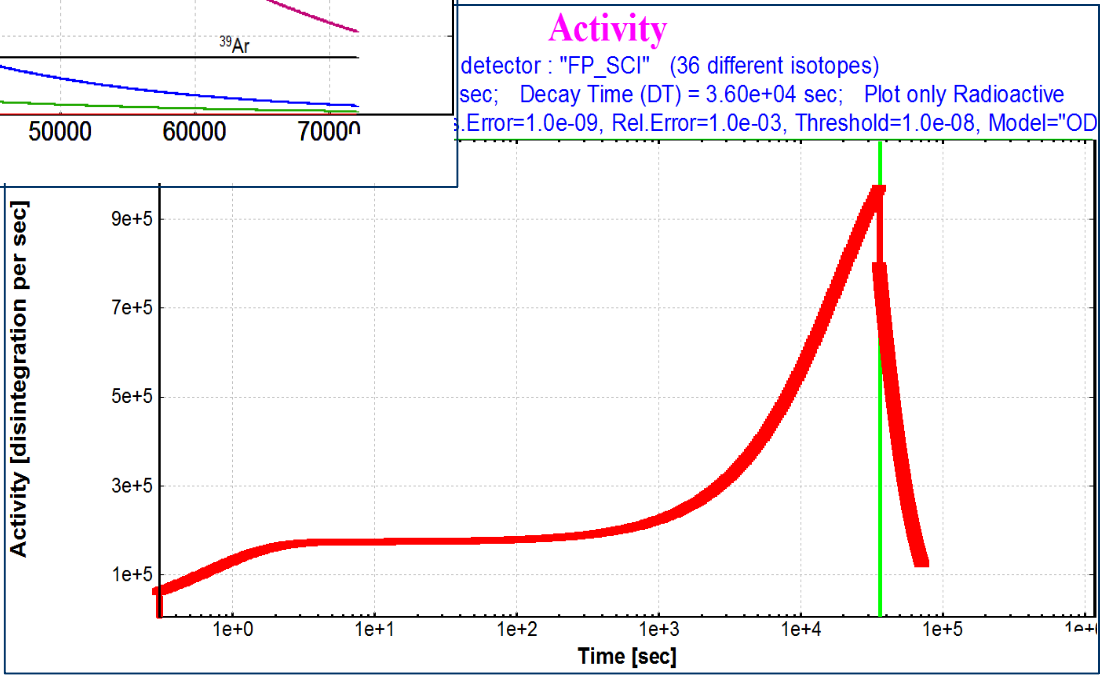
http://lise.nscl.msu.edu/9_10/radiation/44Ti%20from%2058Ni.lpp

10 hours of irradiation, 10 hours of decay :
^{44}Ti's number of atoms is highest!

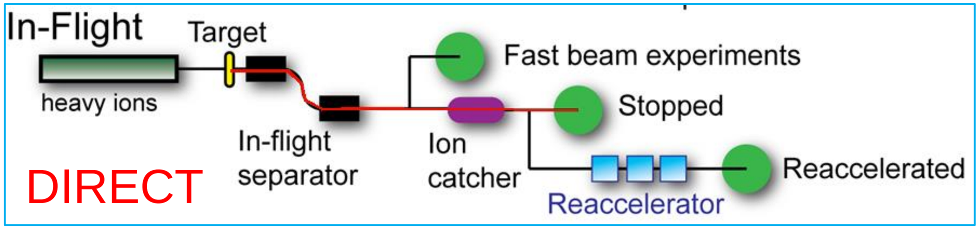


^{44}Ti's case : Evolution of Radiation Residues



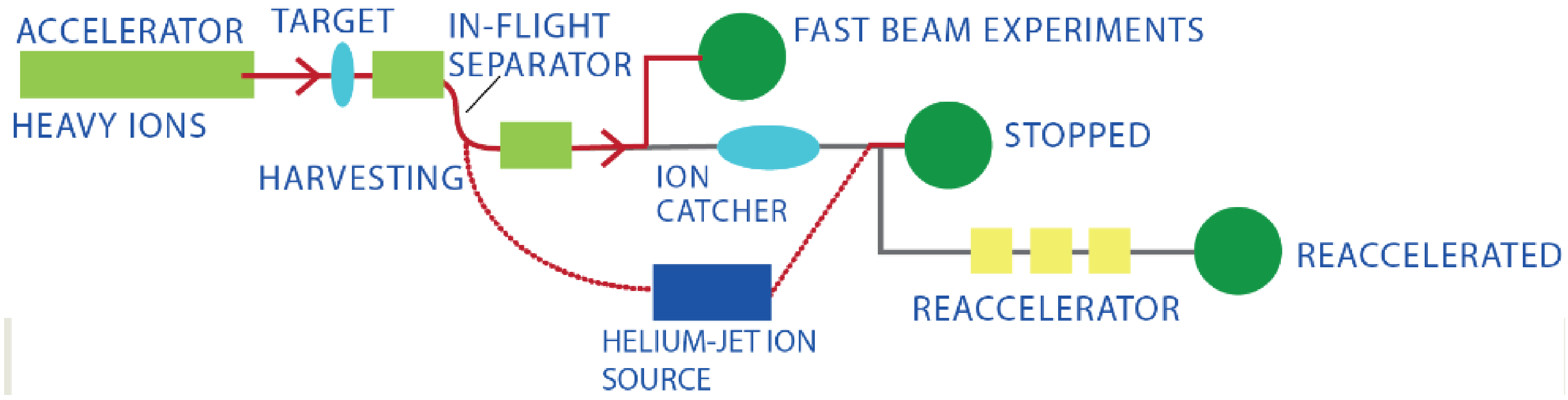


Commensal operation: Helium-Jet Ion-Guide System



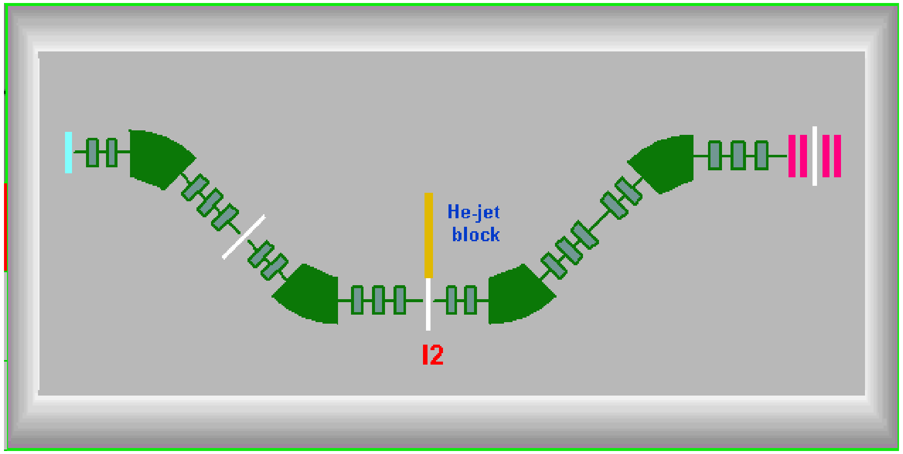
Commensal operation:

- Rare isotopes produced off-axis of the fragment separator are caught in a high-pressure cell filled with a helium-aerosol mixture
- Harvested isotopes are transported to the helium-jet ion source
- Rare isotopes are accelerated, purified and delivered to experimental stations

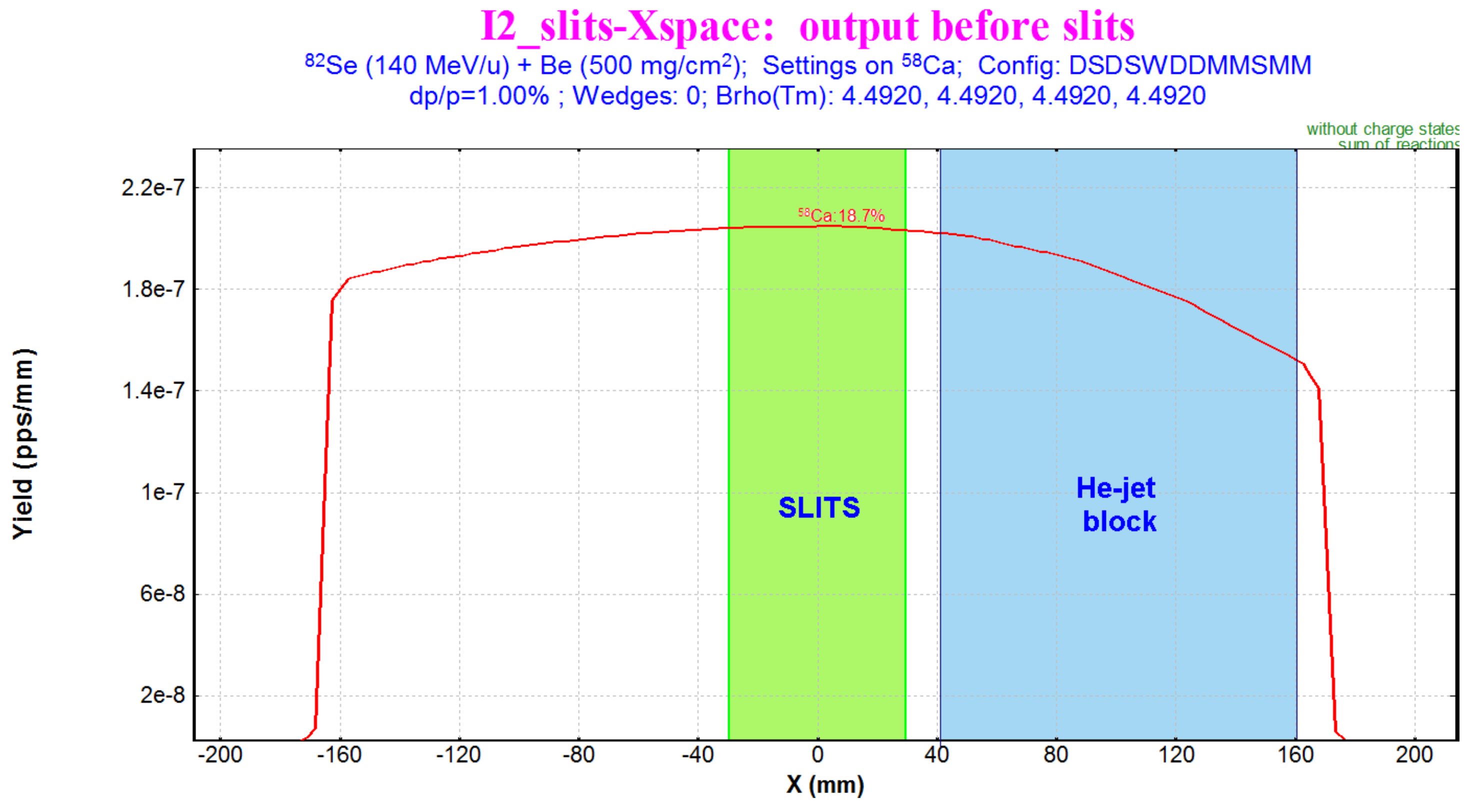


"He-jet" case calculation

Assume the production ^{58}Ca from using the ^{82}Se beam with the A1900 fragment separator, and the He-jet block located at 40-160 mm (I2 position)



http://lise.nscl.msu.edu/9_10/radiation/82Se_58Ca.lpp

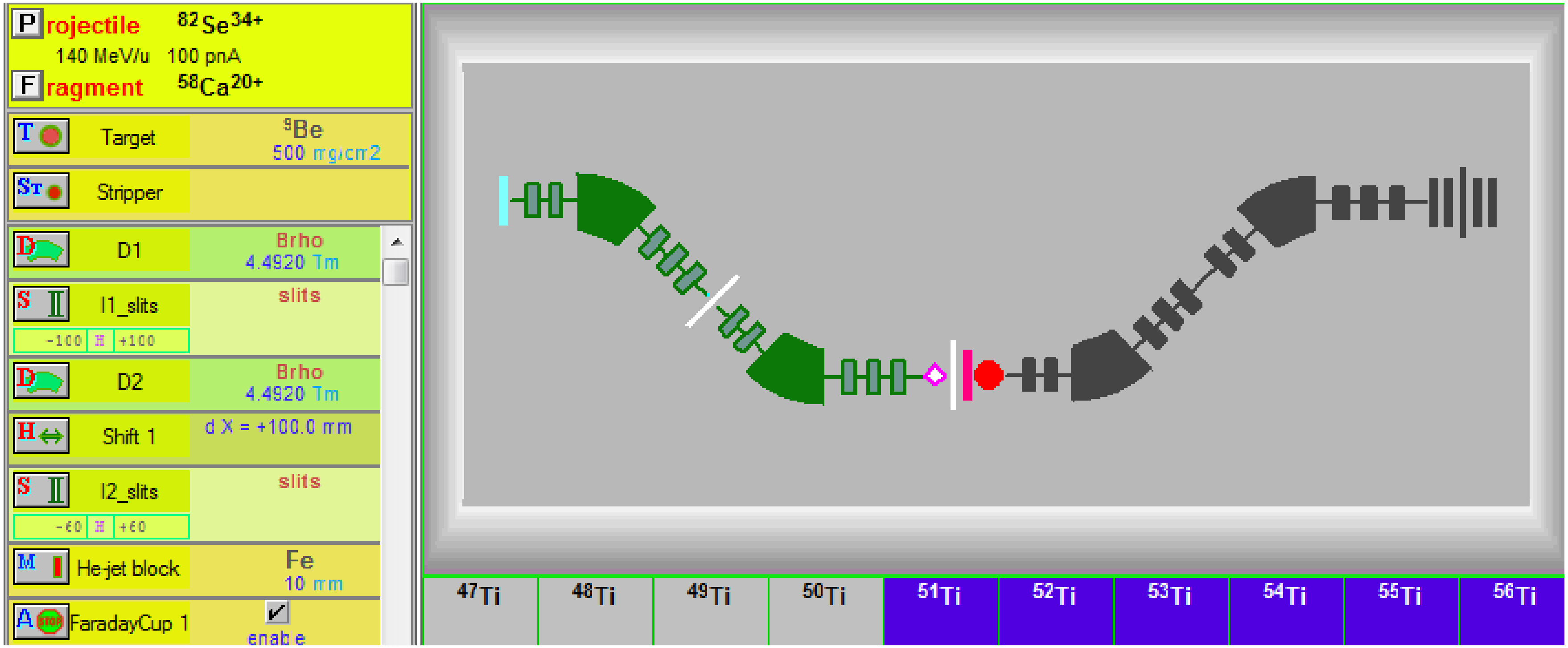


"He-jet" case calculation

Steps to create the "He-jet" configuration from previous case:

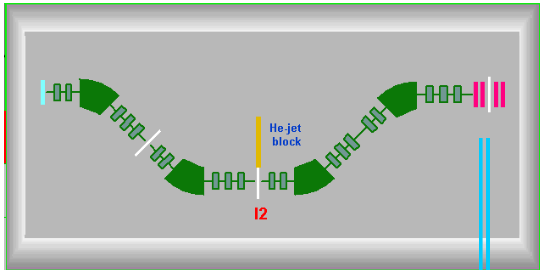
1. Set Width of I2 slits equal to the He-jet block width (+/- 60 mm)
2. Behind the I2 slits insert a thick material enough to stop all products
3. After this material set the Faraday cup
4. Insert the shift block dX=100 mm in front of the I2 slits, assuming the central axis is passing through the center of He-jet block

http://lise.nscl.msu.edu/9_10/radiation/82Se_58Ca_He-jet.lpp

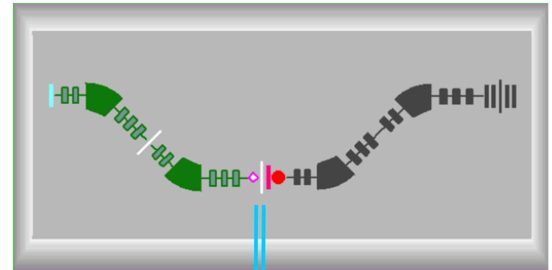


“He-jet” case calculation

82Se_58Ca.lpp

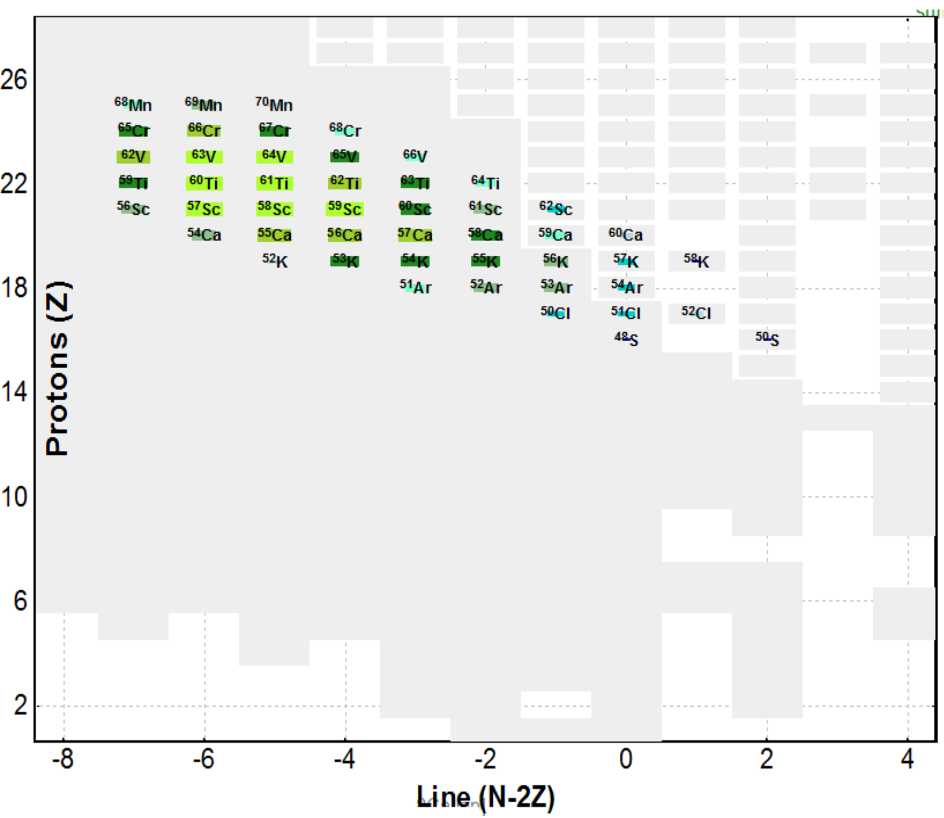


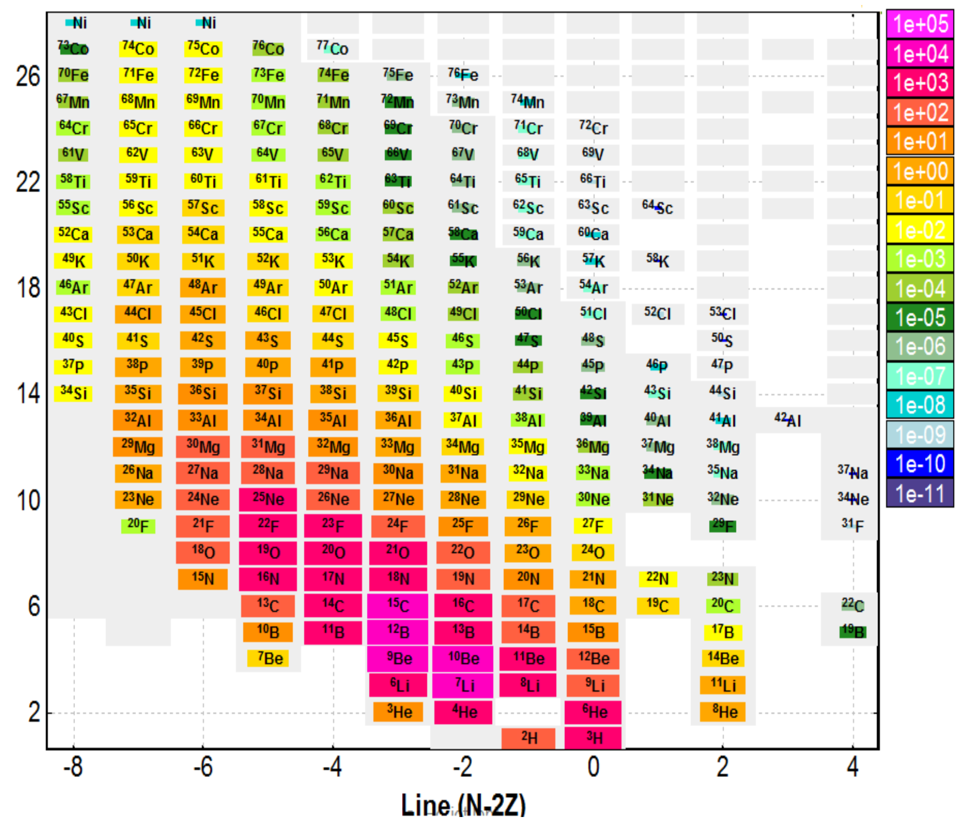
82Se_58Ca_He-jet.lpp



Rate 0.02 pps

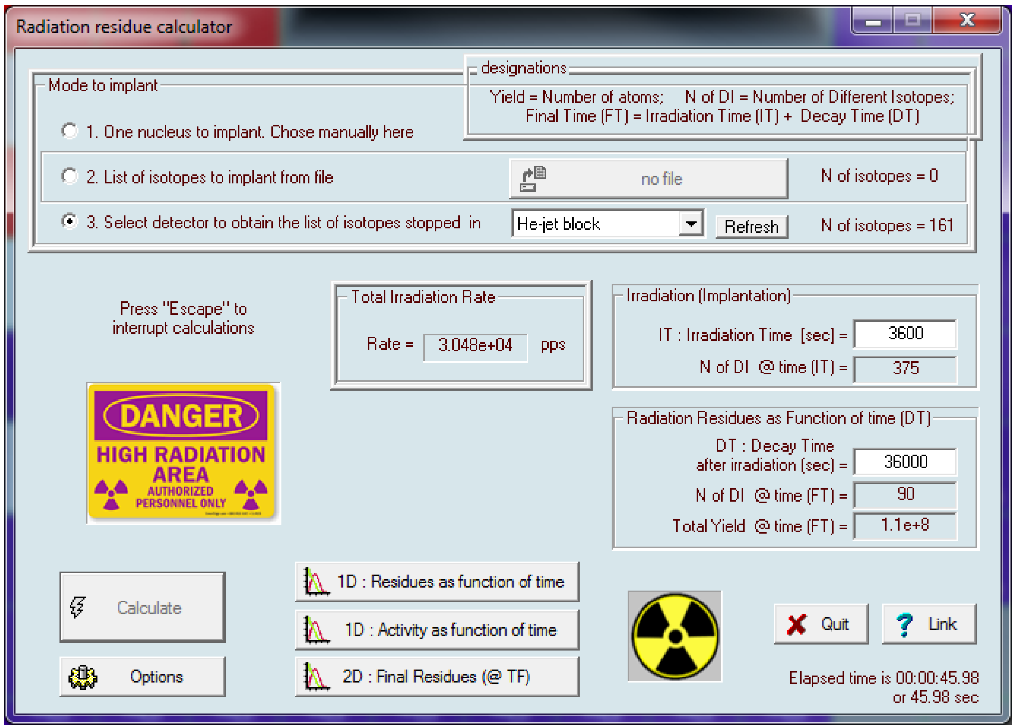
Rate 1.6e5 pps

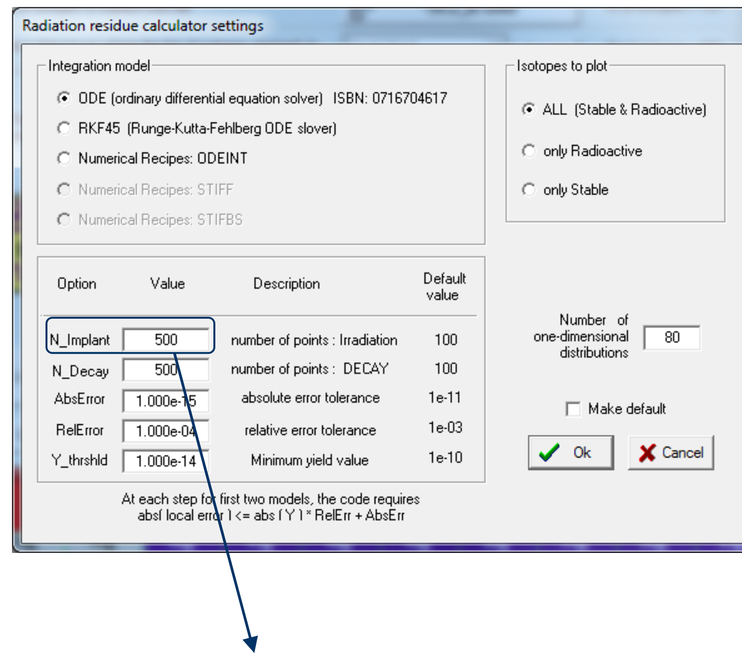




“He-jet” case calculation

1. Calculate all products with new 82Se_58Ca_He-jet.lpp file
2. Call the Radiation Residue Calculator
3. Set the Irradiation and Detector (Transportation) times (for example* 1 & 10 hours)
4. Chose “He-jet block” as detector
5. Click the “Calculation” button

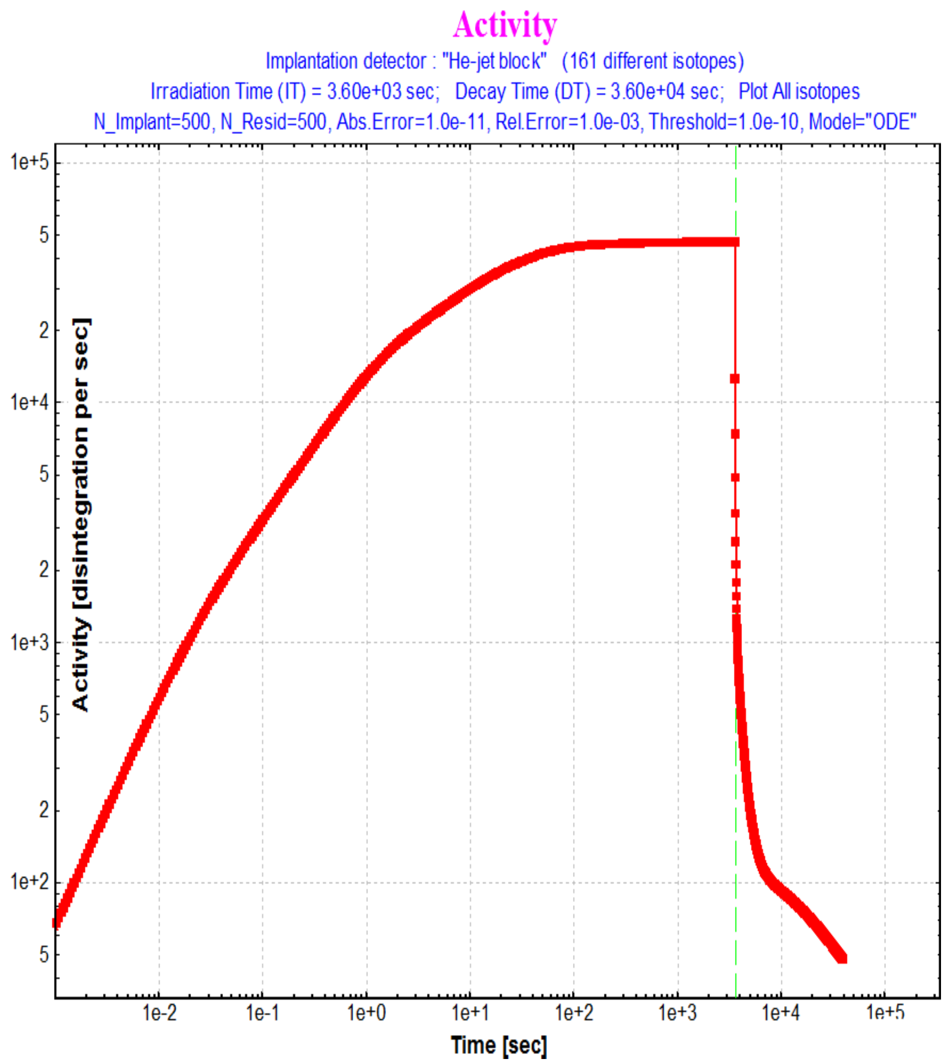


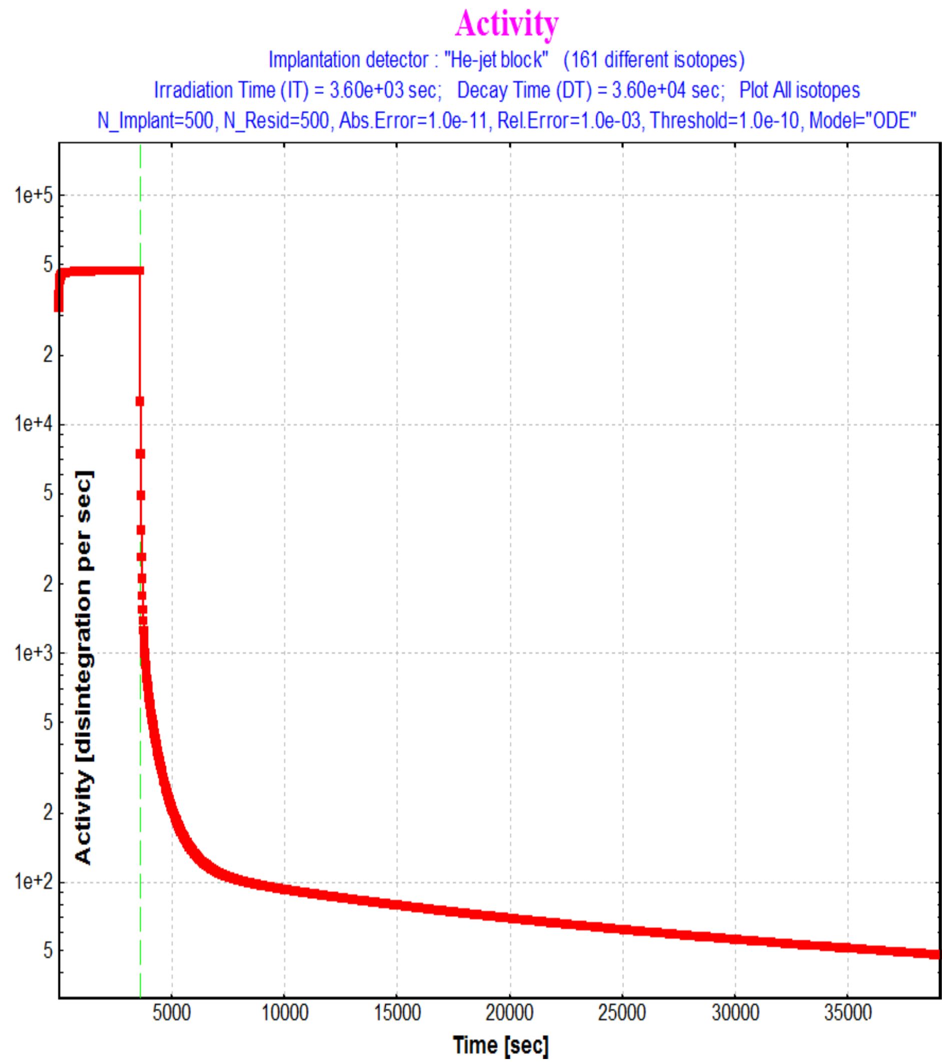


Maximum number of iterations (50000) has been reached for N_implantation=100 for two last implantation steps

* It is a JUST EXAMPLE!

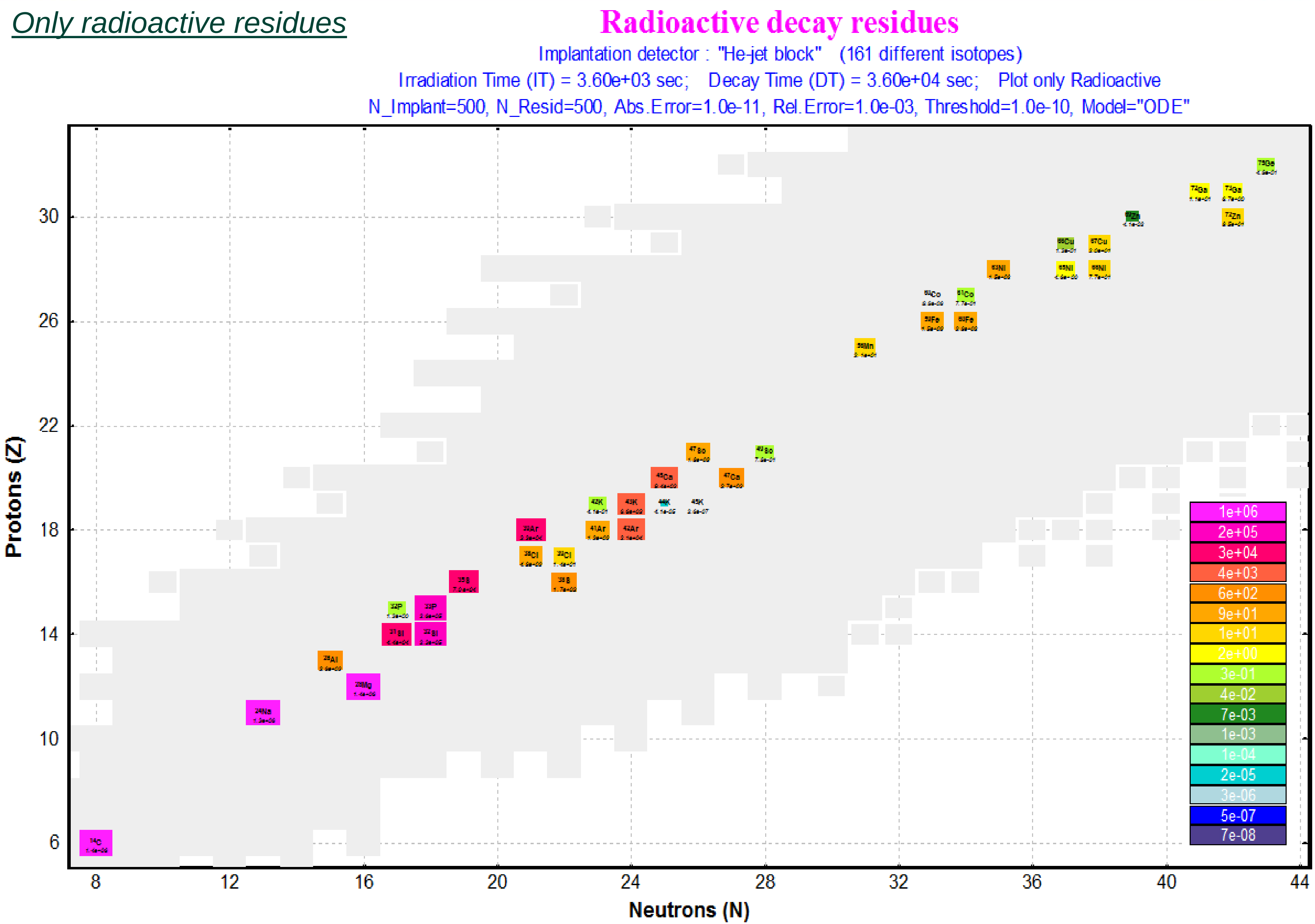
“He-jet” case calculation : Activity





"He-jet" case calculation : Final residue products

Only radioactive residues



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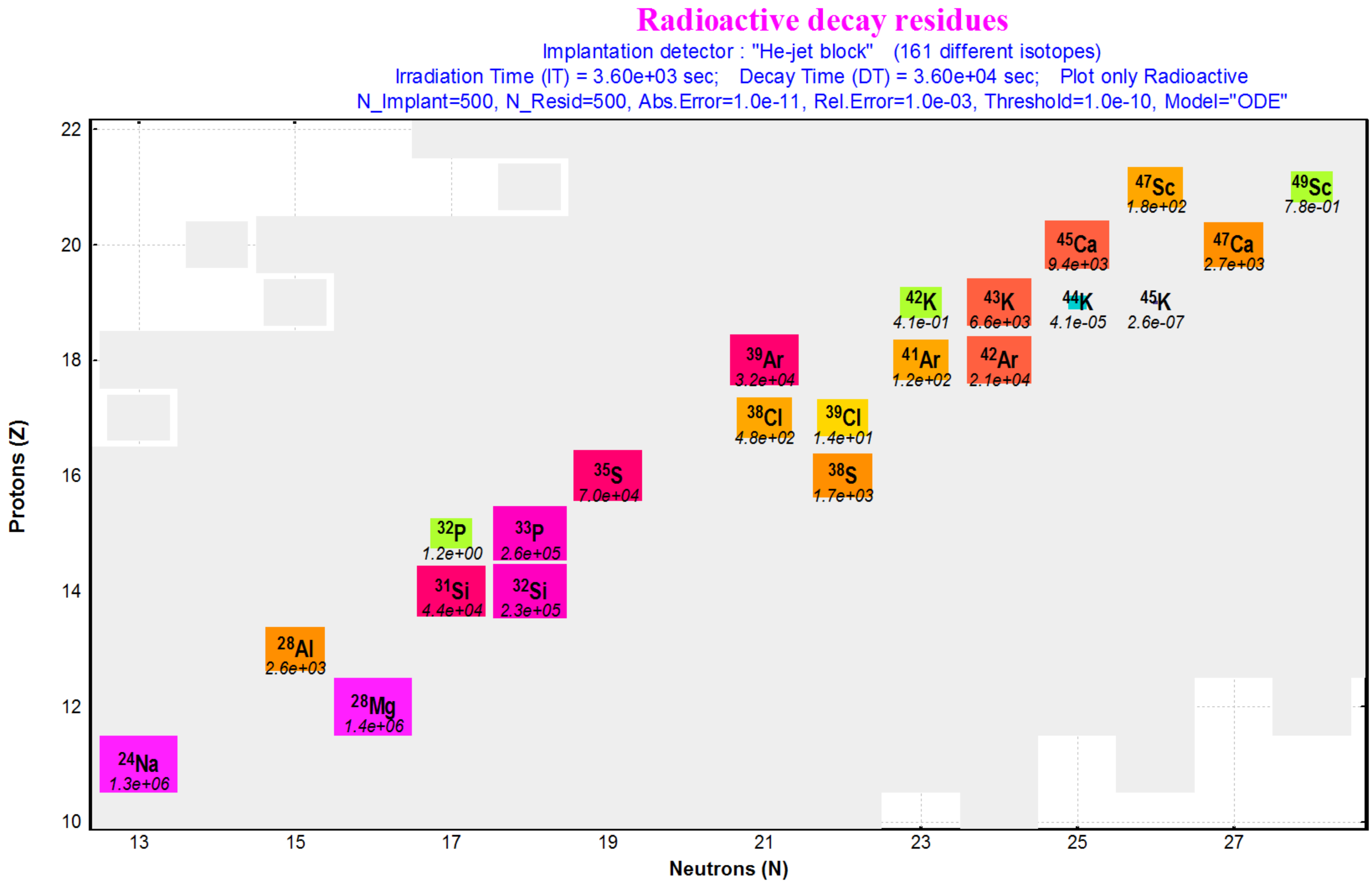

Summary: LISE++ package

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- Current version 9.10.343, 15-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»,
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- ISOL Catcher,
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