ELSEVIER

Nuclear Physics A 701 (2002) 661c–665c

NUCLEAR PHYSICS A

www.elsevier.com/locate/npe

The code LISE: a new version for "Windows"

O. Tarasov [a,b,*], D. Bazin [c], M. Lewitowicz [a], O. Sorlin [d]

[a] *GANIL, BP 5027, 14076 Caen cedex 5, France*
[b] *FLNR, JINR, 141980 Dubna, Moscow region, Russia*
[c] *NSCL, MSU, East Lansing, MI 48824-1321, USA*
[d] *IPN, CNRS-IN2P3, 91406 Orsay cedex, France*

Abstract

The LISE code is intended to simulate medium-energy and high-energy fragment separators with electrostatic and/or magnetic selections. It is based on first-order optics and transport integral convolution techniques. Fragment separators such as LISE3, SISSI/LISE3 and SPEG at GANIL, FRS at GSI, COMBAS and ACCULINA at Dubna, A1200 and A1900 at NSCL, and RIPS at RIKEN are based on the separation of projectile-like fragments, and can be easily simulated via optical configuration files. The reaction mechanism assumed in this program is projectile fragmentation, suitable to simulate experiments at beam energies above 30 *A* MeV. However, built-in tools such as the physical calculator, nucleus database utilities, relativistic reaction kinematics calculations and beam optics transport calculations make it a very useful tool below this energy limit as well. The program can therefore be used for forecasting and tuning experiments using heavy-ion beams with energies ranging from 10 keV up to a few GeV per nucleon.

1. Introduction

The program LISE [1] called after the spectrometer of the same name [2] has been developed to calculate the transmission and yields of fragments produced and collected in a fragment separator. It is intended to simulate the production of Radioactive Nuclear Beams (RNB), from the parameters of the reaction mechanism to the various selections performed by the separator. It allows to quickly optimize the parameters of the separator before and during an experiment. It also serves as a tool for forecasting the intensity and purity of RNB, as well as helps in their identification online. Selection criteria using energy-loss and velocity-filtering techniques are included in the program. Energy loss, time-of-flight,

* Corresponding author.

0375-9474/02/$ – see front matter
PII: S0375-9474(01)01663-3

position, angular, charge, cross-section distribution plots, as well as dE–E, dE–TOF, Z–A/Q and dE–X two-dimensional plots allow to quickly visualize the results of the calculations. An application of the transport integral [3] is the basis of the fast calculations of phase-space distributions.

The program has recently undergone a number of extensive improvements and has been adapted to the "Windows" environment:

- Because it is now implemented in the 32-bit "Windows" operating system, the program has received an improved interface in which the user gets all its graphical-user-interface advantages (work in several windows, etc.).
- It is possible to choose the parameterization of fragmentation cross sections and the ionic charge distributions model.
- The database of nuclide [4] has been incorporated. The user can check the transmission, characteristics and energy of a given isotope by right-clicking on it in the table of nuclides. The database can be modified and its data plotted according to Z, N, A, or N–Z.
- The optical parameters of the separator are entered in a convenient way as standard transport [5] matrices. The initial emittance and energy dispersion of the beam can be modified. The full separator matrix and the beam vector in the intermediate dispersive focal plane and final focal plane can be calculated to check achromaticity conditions. The new version uses the parameters (x/θ) and (y/ϕ) in the optical matrices to calculate a transmission, so focussing is no longer assumed by default.
- The dipole after the velocity filter has been added. It is placed on a moveable platform behind the velocity filter as the final stage of the mass over charge selection (A/Q). This feature allows to use the program to simulate recoil spectrometers.
- It is now possible to choose among different wedge profiles (achromatic, monochromatic, homogeneous, user-defined) in the intermediate dispersive focal plane. All wedge profiles can be converted into angle profiles when thin foil are used.
- A new dialog and plot of relativistic kinematics calculations (two body) is added.

As in the earlier versions, the program allows to quickly calculate the optimal target thickness which maximizes the yield of the fragment of interest. The concept of a dead layer of target has also been incorporated (very important for the case of a thick target to produce light exotic nuclei).

The program can be downloaded freely as a self-extracting archive from anonymous FTP or the web references [1].

2. General features

The *reaction mechanism* assumed in this program is the so-called projectile fragmentation, as pictured, for example, by the abrasion model followed by a sequential evaporation of both projectile and target spectators (fragments). A statistical model based on [6,7] is used to determine the momentum and angular phase space distributions of the projectile fragments. The user can change the values σ_0 and σ_D, the reduced parallel and transverse

momentum widths (the default values are 90 and 200 MeV/c, respectively). The average fragment velocity can be set to a constant value or can be calculated from the expression given by Borrel et al. [8].

The *cross sections* are calculated according to a global parameterization (EPAX [9]) with no energy dependence. Five different built-in parameterizations [9,10] of cross sections based on the EPAX model are available. It is also possible to directly enter the cross section for a given reaction, provided it was previously measured or calculated by more sophisticated codes. Once a cross section is manually entered in the program, it is automatically saved with the results of calculations.

The determination of the *equilibrium charge state* distribution of an ion beam after passing through material can be calculated according to three different parameterizations [11–13]. The first two parameterizations are valid for energies above 5 A MeV, whereas the last one is valid only in the low-energy region. The calculation of charge-state distributions and their corresponding transmissions can be enabled or disabled by selecting the Charge States option. In case it is enabled, the charge states of the fragment of interest have to be specified after the target and the wedge. As a guide in selecting the charge states with maximum intensity, the ionic charge distributions and mean ionic charge after the target, wedge or materials can be plotted.

The calculation of *energy loss* and energy straggling is crucial for deducing magnetic rigidities, transmission of fragments and their ranges in detectors. Two energy-loss calculation methods are available:

(1) helium-based parameterization of Hubert et al. [14] (the starting point at 2.5 A MeV is given by the range tables of Northcliffe et al. [15]);
(2) hydrogen-based parameterization of Ziegler et al. [16].

The energy loss are calculated for atomic numbers ($1 \leqslant Z \leqslant 130$) and energies from 10 keV in materials from hydrogen up to uranium. The calculation of energy loss in gas and composite materials is also included.

It is often necessary to perform fast transformations of a physical value to another while working with the program. The "Physical calculator" window allows to perform calculations of correlated values independently from the rest of the calculations. The mode is selected by radiobuttons, after which the corresponding value can be entered and the calculations automatically performed. The eight correlated quantities of a given ion are the following:

- energy (MeV per nucleon);
- $B\rho$ value (magnetic rigidity) (T m);
- TKE (Total Kinetic Energy) (MeV);
- velocity (cm/ns) and $\beta = v/c$;
- range in a given material chosen by the user in units of mg/cm^2 and μm;
- residual energy of an ion after any material defined by the user.

Most of the options available in the program are well documented in an on-line help. The constant improvements of the code based on the users remarks has brought its high

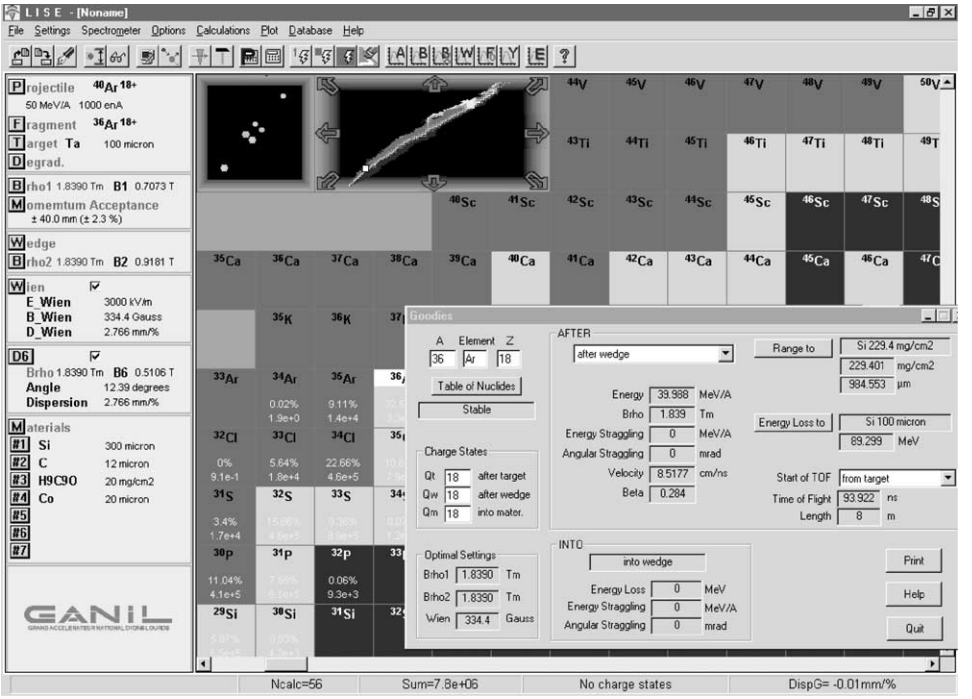

Fig. 1. The LISE code in action.

flexibility and made it well adapted to almost any nuclear physics experiment using magnetic and/or electrostatic separation devices. A paper describing the program more extensively is in preparation [17].

References

[1] The LISE code web sites: http://dnr080.jinr.ru/LISE.html;
The LISE spectrometer web site: http://www.ganil.fr/LISE/prog.html.
[2] R. Anne et al., Nucl. Instrum. Methods A 257 (1987) 215–232.
[3] D. Bazin, B. Sherrill, Phys. Rev. E 50 (1994) 4017–4021.
[4] G. Audi, A.H. Wapstra, At. Data Nucl. Data Tables (1995).
[5] K.L. Brown et al., CERN 80-04.
[6] A.S. Goldhaber, Phys. Lett. B 53 (1974) 306–308.
[7] R. Dayras et al., Nucl. Phys. A 460 (1986) 299–323.
[8] V. Borrel et al., Z. Phys A 314 (1983) 191.
[9] K. Sümmerer et al., Phys. Rev. C 42 (1990) 2546–2561;
K. Sümmerer, B. Blank, Phys. Rev. C 61 (2000) 034607.
[10] O. Tarasov et al., Phys. Lett. B 409 (1997) 64–70;
O. Tarasov et al., Nucl. Phys. A 629 (1998) 605–620.
[11] J. Winger et al., Nucl. Instrum. Methods B 70 (1992) 380;
Y. Baudinet-Robinet, Nucl. Instrum. Methods 190 (1981) 197.
[12] A. Leon et al., At. Data Nucl. Data Tables 69 (1998).

[13] K. Shima et al., Nucl. Instrum. Methods 200 (1982) 605–608.
[14] F. Hubert et al., At. Data Nucl. Data Tables 46 (1990) 1–213.
[15] L.C. Northcliffe et al., Nucl. Data Tables A 7 (1970) 233.
[16] J.F. Ziegler et al., The Stopping and Range of Ions in Solids, Pergamon Press, New York, 1985.
[17] D. Bazin et al., Nucl. Instrum. Methods (2000), submitted.