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Development of tools and techniques for momentum compression of fast rare isotopes

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The most recent results described here are built on the research during FY05 through FY07 supported by this grant in three major areas: (1) the design and simulation of projectile fragment separators, (2) the development of the LISE++ simulation code, and (3) obtaining data to benchmark the simulation code through experimental work at the NSCL. Examples of the work carried out by our group during the preceding three years as part of this grant includes the development of the simulation code that was essentially continuous during this period with releases of major revisions of the code in September/2005, in April/2007, in April/2009 and the current version described below in August/2010. The experiment to obtain the benchmarking data was proposed and approved by the NSCL PAC at the end of 2005, was carried out in April/2007 and the analyzed since that time.

The supported research during the concluding period of this grant in FY08 with a no-cost extension into FY09 consisted of two tasks related to rare isotope facilities using projectile fragmentation and gas catchers: (1) to further develop the LISE++ simulation code and (2) to fully benchmark all aspects of the LISE++ code. Both of these tasks are substantially complete. This work was carried out with input from the leading experts in the US, Germany and Japan that was facilitated by an “experts meeting” held at the NSCL in 2008.

Task (1):

As part of our past research and development work, we have created and developed the LISE++ simulation code [Tar04, Tar08]. The LISE++ package was significantly extended with the addition of a Monte Carlo option that includes an option for calculating ion trajectories using a Taylor-series expansion up to fifth order, and implementation of the MOTER Monte Carlo code [Kow87] for ray tracing of the ions into the suite of LISE++ codes. The MOTER code was rewritten from FORTRAN into C++ and transported to the MS-Windows operating system. Extensive work went into the creation of a user-friendly interface for the code. An example of the graphical user interface created for the MOTER code is shown in the left panel of Figure 1 and the results of a typical calculation for the trajectories of particles that pass through the A1900 fragment separator are shown in the right panel. The MOTER code is presently included as part of the LISE++ package for downloading without restriction by the worldwide community.

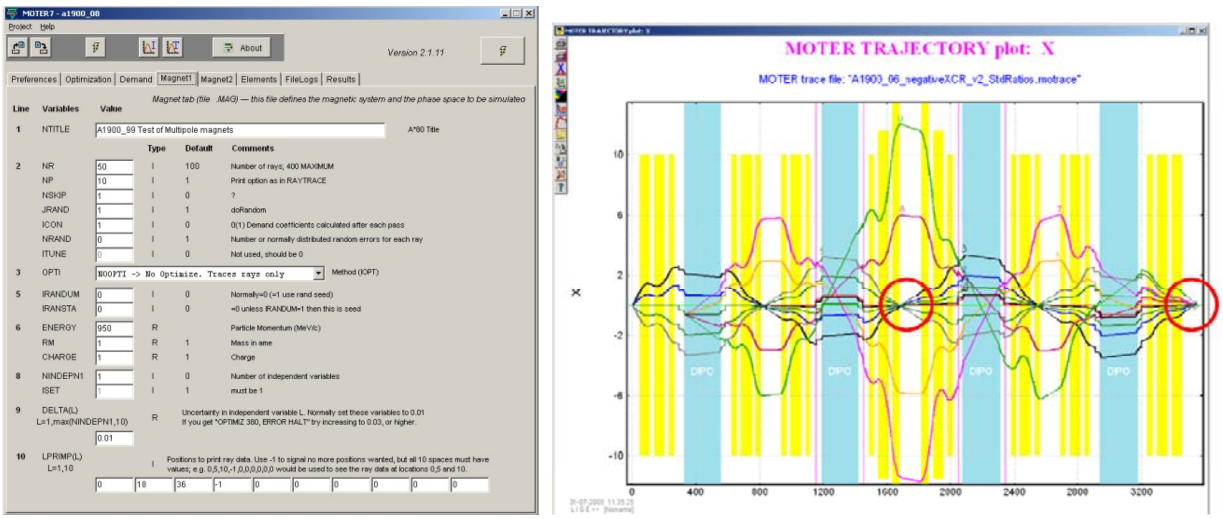

Figure 1, (left) Example of the user interface to the LISE++ version of MOTER, and (right) example graphical output of the MOTER code for particles traversing the A1900 fragment separator in the dispersive (x) dimension.

The LISE++ was extensively developed and generalized to apply to any projectile fragment separator during the early phase of this grant. In addition to the inclusion of the MOTER code, other important additions to the LISE++ code made during FY08/FY09 included:

- Version 8.0 included extensive development of Monte Carlo techniques to propagate ions through the magnetic systems in the LISE++ package. Before the present work, analytical equations were used by LISE++ to describe the distributions of particles in phase space which were transformed by matrix representations of the system. The distributions of particles were thus limited by the analytical functions. As the first step in removing these limitations, a Monte Carlo technique was developed to follow the ion motion through the system using first-order matrix algebra. In addition, this version included calculation (and output) of the energy deposited in materials as a function of position in 3D by fragments. Control of these ionization distributions is critical for ion-stopping in gas catchers. Excellent agreement was found between the predictions and measurements with the NSCL gas cell.

- Version 8.4 incorporated higher order ion-optics into the LISE++ transmission calculations. With the development of the Monte Carlo technique, the first-order ion optics was extended up to fifth order (with the requirement of suitable descriptions of the magnetic fields). The extension allows visualization of ion-optical aberrations and the effects of angular acceptances, for example, that were not possible in the simpler code. An example of the improvement in the predicted fragment yields is shown in Figure 2 for some of the data obtained as part of this project. The figure shows the dramatic reduction in the transmission of this fragment through the A1900 caused by second and third order aberrations.

- Version 9.1 is compatible with the 64-bit Microsoft operating system.

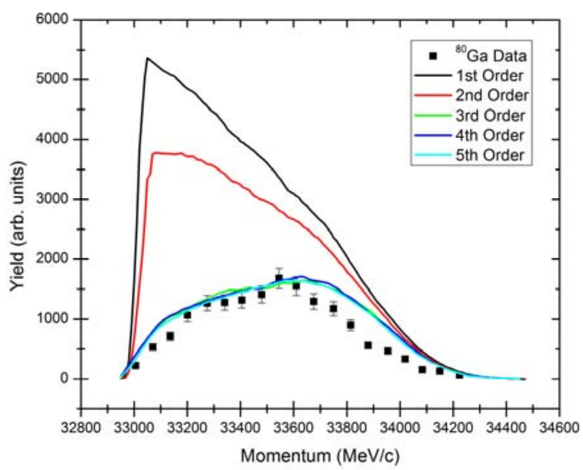

Figure 2, A comparison of the observed momentum distribution of ^{80}Ga fission fragments with the predictions of the LISE++ Monte Carlo calculations showing the effect of increasing the order of the ion-optical corrections.

The LISE++ is distributed over the web (http://groups.nscl.msu.edu/lise) and is available without charge to anyone by anonymous download, thus, the number of individual users is not recorded. The number of "hits" on the servers that provide the LISE++ code is shown in Figure 3 for the last eight calendar years (left panel) along with the country from the IP address (right panel). The data show an increase in web-activity with the release of the new version of the program during the grant period and a world-wide impact.

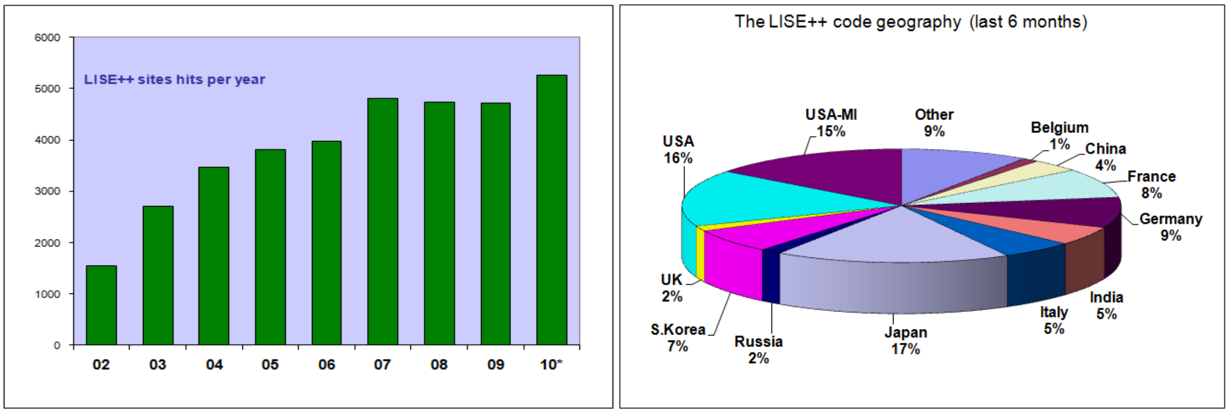

Figure 3, (left) Number of web hits on the LISE++ servers from 2002 to 2010, and (right) geographical distribution of web hits during the last six months.

Task (2):

An important part of the proposed work carried out during FY07, FY08 and FY09 by a graduate student in the MSU Physics program was to benchmark the codes by comparison of detailed measurements to the LISE++ predictions. A large data set was obtained for fission fragments from the reaction of ^{238}U ions at 81 MeV/u in a 92 mg/cm^2 beryllium target with the A1900 projectile fragment separator. The data were analyzed and form the bulk of a Ph.D. dissertation that is nearing completion. The rich data set provides a number of benchmarks for the improved LISE++ code and only a few examples can be shown here. The primary information obtained from the measurements is the yield of the products as a function of mass, charge and momentum. Examples of the momentum distributions of individually identified fragments can be seen in Figures 2 and 4 along with comparisons to the predicted distributions. The agreement is remarkably good and indicates the general validity of the model of the nuclear reactions producing these fragments and of the higher order transmission calculations in the LISE++ code. The momentum distributions were integrated to provide the cross sections for the individual isotopes. As shown in Figure 5, there is good agreement with the model predictions although the observed cross sections are a factor of five or so higher in this case.

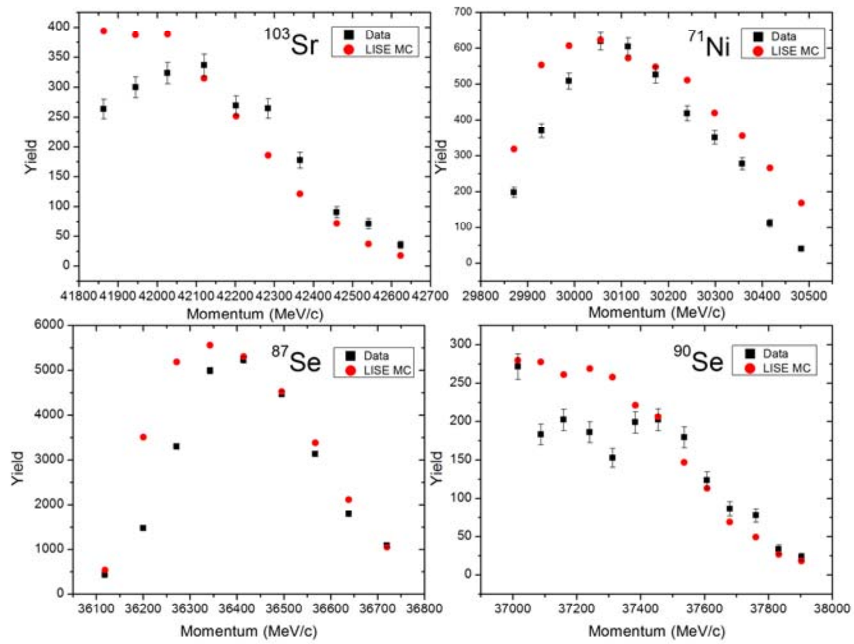

Figure 4, A comparison of the measured momentum distributions of four neutron-rich fission fragments from this reaction (black squares) with the predicted distributions from the LISE++ Monte Carlo version (red circles).

Other comparisons of measured production cross sections from abrasion-fission reactions have been published by our group working at the NSCL during this period [Fol09] and through our collaboration with Japanese researchers working at RIKEN with the BigRIPS separator [Ohn08, Ohn10]. The agreement of the model predictions with the data obtained with two different fragment separators is very good and indicates the usefulness of the new LISE++ code.

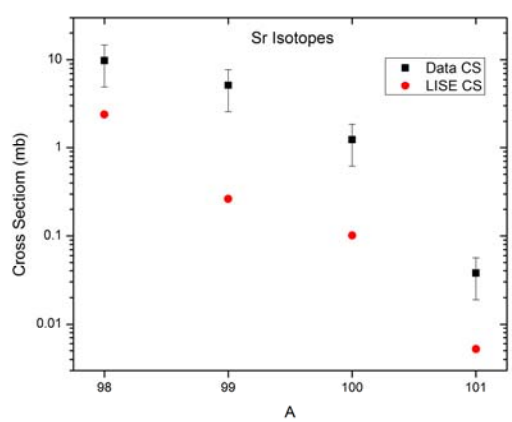

Figure 5, the cross sections for the strontium isotopes observed in this work compared to the cross sections from the Abrasion-Fission model implemented during the grant period in the LISE++ code.

Experts Meeting:

A series of workshops on technical aspects of projectile-fragment separators was inaugurated by the FRS group at GSI (Germany) and us in 2004 to foster collaborative efforts to solve a number of significant issues in the next generation fragment separators. The second workshop hosted by the BigRIPS group at RIKEN (Japan) in 2006 (FY07) and our group attended that meeting, presented our work and obtained important input from colleagues. In order to further facilitate the present DOE sponsored research, we hosted the third Fragment Separators Experts workshop at the NSCL from March 31st to April 2nd, 2008. The meeting was an intensive two and one-half day forum of thirty-six experts in the design, construction, and operation of electromagnetic projectile fragment separators. The program of the workshop and other information can be found on the workshop website: http://meetings.nscl.msu.edu/fse08 The workshop participants came from Argonne National Lab (3), Oak Ridge National Lab (1), the GSI (5), RIKEN (6), and the NSCL (20). The presentations with extensive discussion covered ion-optics of next-generation separator designs, superconducting magnet design and construction, new developments for high intensity target design, high power beam dumps, radiation shielding and various system control and operational issues. The next workshop is scheduled to be held at GSI in December, 2010.

References:

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