LISE++ development: Fusion-Fission

* LISE++ new reaction mechanism: Fusion-Fission

* LISE++: combination of consecutive transmission product calculation for several reactions

Version 7.8.87 beta from 6/6/6 available through LISE sites
LISE++ new reaction mechanism: Fusion-Fission

1. No angular momentum contribution
2. Fission cross section is taken without pre-fission neutrons

Fusion from “Fusion-Residual”

Fission from “Abrasion-Fission”

Transmission probability for a one-dimensional potential barrier

- Classical
- Quantum-mechanical

h_omega - Curvature parameter of the parabolic potential describing the barrier (default value 5 MeV)
Calculated fusion-fission cross sections are kept in memory.

Break-up and fission channel cross sections in the Fusion information dialog (Fusion-Residual reaction).
Fusion-Fission kinematics (after target)

Monte Carlo

LISE analytical
Fusion-Fission kinematics (after target)

Monte Carlo

LISE analytical

174Yb fragment kinematics (expected final)

Stripper-Angle: x'output

Dipole 1-Energy: Input

174Yb (20.0 MeV/u) + Be (0.5 mfp). Settings on 174Yb: Config. SS1/SS11/11, 50% Strip.  Pitch 1.9, Distance 1. PT1, 1.715

Initial angular emittance +25 mrad (SISSI)

June 16, 2006. NSCL/MSU
Angular acceptance

Monte Carlo

LISE analytical

174Yb fragment kinematics (expected final)

Statistics 132Yb

132Yb Unknown (Z=70, N=112)

Production Rate (ppb) 3.51e-6
Reaction FuPFe
Sum of reactions (ppb) 3.51e-6
Q in the target (MeV) 1.98e-5
Total transmission (%) 4.25

Target (%)
Unreacted in meter. (%) 100
Unstopped in meter. (%) 100
Dipole 1 (%) 58
X angular transmission (%) 1.05
Y angular transmission (%) 75.24
SlitsDisp (%) 8.71
X space transmission (%) 8.75
Y space transmission (%) 99.6
Dipole 2 (%) 84.1

Dipole 1-DebugFission

June 16, 2006  NSCL/MSU
Angular and Momentum acceptances

Angular acceptance (2)

Monte Carlo

LISE analytical

Momentum acceptance

Monte Carlo

LISE analytical
$^{238}$U + d: data and LISE calculations (1)

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<th>Elab (MeV/u)</th>
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<th>Excitation (MeV)</th>
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Fusion barrier = 12.5 MeV

LISE++ calculations
- total Bass
- fusion (quantum-mech. $h_0=5$ MeV)
- Fusion-Fission (without prefission neutrons)
- Fusion-Breakup

[d+$^{238}$U] - Stevenson et al., PR 111 (1958) 886

Fission channel cross-sections
- total complete fusion - fission cross section is equal to 1310 mb
$^{238}\text{U} + d \rightarrow \text{ff} \rightarrow ^{157}\text{Eu}$

$^{238}\text{U} + d \rightarrow \text{ff} \rightarrow ^{156}\text{Eu}$

$^{238}\text{U} + d \rightarrow \text{ff} \rightarrow ^{153}\text{Sm}$

$^{238}\text{U} + d \rightarrow \text{ff} \rightarrow ^{164}\text{Eu}$
**238U + C : data and LISE calculations**

**Fusion and fusionlike process**
A.Gavron et al., PRC 30 (1984) 1550

**FIG. 8.** Angular distribution of fission fragments for ¹²C at 95 MeV. Circles, on ¹⁷⁴Yb; squares, on ¹⁹⁷Pt; triangles, on ²³⁸U. Lines are results of calculations using the transition state model. Alternate systems have solid and dashed lines to improve readability.
$^{238}\text{U} + ^{16}\text{O}$: data and LISE calculations

Fusion and fusionlike process
A. Gavron et al., PRC 30 (1984) 1550
\[ ^{142}\text{Nd} + ^{16}\text{O} : \text{data and LISE calculations (1)} \]

**LISE++ calculations**
- total Bass
- fusion (quantum-mech. $E_0=5\,\text{MeV}$)
- Fusion-Fission (without pre-fission neutrons)
- Fusion-Fission
- "Fusion-Breakup"

[\[^{16}\text{O} + ^{142}\text{Nd}\] - A.Gavron et al., PRC 30 (1984) 1550]

**Fission barrier?** "FisRot" (Cohen) was used default

**Fusion and fusionlike process**
A.Gavron et al., PRC30 (1984) 1550
$^{142}$Nd + $^{16}$O: data and LISE calculations (2)

Fission barriers at $L=0$ for $Z=68$ isotopes

LISE calculations without angular momentum contribution do not reproduce well this region!

FIG. 17. Schematic partial wave distribution for the $^{16}$O+$^{142}$Nd reaction. ER (evaporation residues) and FIS (fusion) label regions of complete fusion which lead to evaporation residues and fission, respectively. $^4$He and $^8$Be label regions of incomplete fusion which, after emission of these particles, end up predominantly in the ER region.
\[ ^{238}\text{U} + ^{32}\text{S} : \text{data and LISE calculations} \]

**Graph:**
- **Axes:**
  - \( \sigma \) (mb) on the y-axis
  - Center of mass energy, MeV on the x-axis

**Table:**

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<th>Excitation (MeV)</th>
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Fusion barrier = 161.84 MeV

**LISE++ Calculations**
- Total Bessel
- Fusion (quantum-mech. \( \hbar = 5 \) MeV)
- Fusion-Fission (without pre-fission neutrons)
- "Fusion-Breakup"
- \([ ^{32}\text{S} + ^{238}\text{U} \) - A. Gavron et al., PRC 30 (1984) 1550
- Fusion-Fission
Combination of consecutive transmission product calculation for several reactions

Notes

- Coulomb fission is included in Abrasion-Fission
- Use the Abrasion-Ablation model instead EPAX for the Projectile fragmentation mechanism in the case of consecutive calculations
- Preliminary check excitation energy region settings for Abrasion-Fission mode
Combination of consecutive transmission product calculation

$^{238}\text{U}(40\text{MeV/u}) + C \rightarrow \text{Fusion or Abrasion ??}$

Cross sections (Fusion $\rightarrow$ Fission)

Cross sections (Fusion $\rightarrow$ Residual)

Cross sections (Abrasion–Fission (Low+Middle+High))

Cross sections (Projectile Fragmentation)
Combination of consecutive transmission product calculation

\[ ^{238}\text{U}(40\text{MeV/u}) + C \rightarrow \text{Angular acceptance} \]