In-beam Fission Study at JAEA

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In-beam Fission/Reaction Studies

(1) Fusion-fission and quasifission

(2) Multi-nucleon transfer induced fission
Access to Neutron-rich SHN

$^{238}\text{U} + ^{248}\text{Cm} (\ 6\text{MeV/u})$

by V. Zagrebaev (FLNR)
Multi-nucleon Transfer Reaction

- Producing many nuclei including neutron rich isotopes
- Populating large-range excitation energies

What we will learn?
- Transfer reaction mechanism
- Fission (survival) probability
- Fission barrier height
- Fission process
- ...

Starting a campaign from $^{18}\text{O} + ^{232}\text{Th}$, $^{238}\text{U}$, $^{248}\text{Cm}$, $^{237}\text{Np}$, $^{249}\text{Cf}$
Future $^{22}\text{Ne}$, $^{26}\text{Mg}$, … beams
New beam line for reaction and fission study using radioactive materials (Np, Am, Cm, Cf, …)

- Multi-nucleon transfer reaction and fission
- Fusion-fission & quasifission

- Identification of Transfer Channels
- Fission Fragments Mass & Angular Distribution
- Neutrons from Fragments and reaction process
- …
Setup for multi-nucleon transfer induced fission

- Target
- $^{18}\text{O}$ Beam
- $^{238}\text{U}^*$
- $^{16}\text{O}$...
- $^{240}\text{U}^*$...

$\Delta E = 75\mu m$

$E = 300\mu m$
Particle Identification

$^{18}\text{O} + ^{238}\text{U} \ (E_{\text{beam}}=157.5 \text{ MeV})$

Diagram showing various particle identification markers and isotopes:
- Pa
- U
- Np
- Pu
- Am

E (MeV) vs. dE (MeV) plot with isotope ranges:
- 237-240
- 239-242
- 241-245

Isotopes and elements:
- 16-19
- 14-17
- 11-15
- 16-19
Fission Barrier and Fission Probability

\[ ^{18}\text{O} + ^{238}\text{U} \rightarrow ^{16}\text{O} + ^{240}\text{U}^* \]

- **16O Events**
- **16O coincided with fragments**

**Excitation Energy (MeV)**

- **Events / 0.5 MeV**
- **Fission Probability**
Fission Fragment Mass Distribution

Data from $^{18}\text{O} + ^{238}\text{U}$ ($E_{\text{beam}} = 157.5$ MeV)
Shell correction energy and Fission

Liquid Drop Model

Corrected for Shell Energy

\[ \Delta E_{Shell}(E^*) = \Delta E_{Shell}^0 \times \exp \left( -\frac{E^*}{E_D} \right) \]

High Excitation Energy

Low Excitation Energy

Shell Damping Energy
Langevin Calculation

Two center shell-model: (Liquid Drop + Shell Correction)
- Charge center distance
- Mass-asymmetry
- Deformation

Trajectory (shape evolution) is calculated by solving Langevin equations.

$$\Delta E_{Shell}(E^*) = \Delta E_{Shell}^0 \exp\left(\frac{-E^*}{E_D}\right)$$

$$E_D = 20 \text{ MeV} : \text{Shell Damping Energy}$$

Y. Aritomo and S. Chiba
Prompt neutron multiplicity

\[ {}^{18}\text{O} + {}^{238}\text{U} \rightarrow {}^{17}\text{N} + {}^{239}\text{Np}^* \]

\[ \nu_{\text{th}} = 2.51 \]

\[ B_n = 6.21 \text{ MeV} \]

$\nu_{\text{th}} \approx 2.51$
Fission fragment angular distribution

- Fissioning Nuclei \((A, Z)\)
- Excitation energy \(E^*\)
- Spin and its projection to the symmetric axis \((L, K)\)
Summary

(1) Beam lines for reaction and fission study using RI material

(2) Multi-nucleon transfer reaction and fission

(3) Fragment mass distributions and shell damping energy

(4) Neutron multiplicity in fission

(5) Fragment angular distributions
A. Andreyev, D. Jenkins
T. Ohtsuki, K. Hagino
S. Chiba, Y. Aritomo
S. Yan
N. Tamura, S. Goto
Y. Watanabe
S. Hofmann, D. Ackermann, F.P. Heßberger, S. Heinz, J. Khuyagbaatar, B. Kindler, V.F. Comas J.A. Heredia, I. Kojouharov, B. Lommel, R. Mann, Ch.E. Düllmann