Production of medium-mass neutron rich nuclei.
From in-flight to two-step scheme

David Pérez Loureiro

Universidade de Santiago de Compostela
The nuclear Landscape

Why explore the limits of nuclear stability?

- Changes in shell structure (new magic numbers and shell quenching)
- Nucleosynthesis
- New phenomena (halos, proton radioactivity)
Motivation

Nuclei around N=82 are very important for investigating evolution of shell structure with neutron excess and their implication with the stellar nucleosynthesis in the r-process.

How to produce RIBs of these medium mass neutron-rich nuclei?
Production of Medium A n-rich nuclei

- **In-flight**
  - Fission of actinides
  - Fragmentation of neutron rich stable beams ($^{136}$Xe)

- **ISOL**
  - Fission of actinides
  - Two step reaction
In-Flight Fission at high and low excitation energy

Low energy fission (Pb), produces very asymmetric mass distributions,
High energy fission (Be) produces a more symmetric distribution of fragments

Pb fission enhances the production of neutron-rich nuclei compared to fission induced by Be

J. Benlliure et al. NPA 628 (1998) 458
Fragmentation of stable beams

Experimental technique:
Projectile fragmentation in peripheral heavy-ion collisions at relativistic energies:

Cold Fragmentation channel is selected:
- Mainly abrasion of protons
- Low excitation energy

Data obtained allow us to benchmark models

David Pérez Loureiro
Generally production cross sections are larger in fission than in fragmentation. In the case of symmetric fission residues (Pd) fragmentation becomes a competitive mechanism.
ISOL Technique

From fission and spallation reactions

In target production studied using inverse kinematics

J. Taieb, M. Bernás, M.V. Ricciardi et al., GSI, IPNO

Efussion, diffusion and extraction efficiency have to be taken into account

Francium production in p(1 GeV) + ²³⁸U
ISOL Technique limitations

Refractory elements, due to high melting point are not extracted efficiently from production target.

Post acceleration stage proposed in order to overcome this problem.
Two step Scheme

1. Production of $^{132}$Sn/$^{84}$Se by fission in a UC$_x$ target

2. Produce medium-mass neutron-rich nuclei via cold fragmentation of $^{132}$Sn/$^{84}$Se
Two Step Experiment

F0-F2: $^{238}\text{U}(950 \text{ A MeV}) + \text{Pb} \rightarrow ^{132}\text{Sn}$

$B\rho \propto \gamma \beta \frac{A}{Q}$

$\Delta \frac{B\rho}{\rho} \sim 3 \times 10^{-4}$
$\Delta \text{ToF} \sim 72 \text{ ps}$
$L \sim 18 \text{ m}$

$\Delta \frac{A}{A} \sim 1.3 \times 10^{-3}$

F2-F4: $^{124-132}\text{Sn} + \text{Be} \rightarrow X$

$\Delta \frac{B\rho}{\rho} \sim 3 \times 10^{-4}$
$\Delta \text{ToF} \sim 100 \text{ ps}$
$L \sim 36 \text{ m}$

$\Delta \frac{A}{A} \sim 1 \times 10^{-3}$

Zakopane, September’08
Two Step Experiment

Experimental setup at dispersive focal plane

Experimental setup at achromatic focal plane

David Pérez Loureiro
Two Step Experiment

All reaction products are isotopically resolved in dispersive and achromatic focal planes of the Fragment Separator
Two Step Experiment

Fragmentation of $^{132}$Sn

Preliminary!
Conclusions

- Medium mass neutron-rich nuclei play an important role in nuclear structure and nuclear astrophysics investigations.
- In-flight fragmentation/fission have been used for producing such nuclei and data collected allow benchmarking and developing of codes with high predictive power.
  - Low Energy fission (Pb) enhances the production of neutron rich nuclei.
  - Fission leads to larger production cross section than fragmentation of $^{136}$Xe except for symmetric fission residues (around Pd) where fragmentation becomes competitive.
- A two step reaction scheme based on fission+cold fragmentation has been proposed and investigated for the production of RIBs of refractory elements.
- Fragmentation of very neutron-rich fission products has been investigated for first time.
- Preliminary cross sections have been measured for $^{132}$Sn fragmentation residues.
S294 collaboration

D. Pérez Loureiro¹, H. Álvarez-Pol¹, J. Benlliure¹, B. Blank², E. Casarejos¹, D. Dragosavac³, V. Föhr⁴, M. Gascón¹, W. Gawlikowicz⁵, A. Heinz⁶, K. Helariutta⁷, A. Kelić⁴, S. Lukić⁴, F. Montes⁴, L. Pienkowski⁵, K.-H Schmidt⁴, M. Staniou⁴, K. Subotić³, K. Sümmерer⁴, J. Taieb⁸, A. Trzcinska⁵

(1) Universidade de Santiago de Compostela, Spain, (2) Centre d’Etudes Nucleaires Bordeaux-Gradignan, France, (3) VINCA-Institute Belgrade, Serbia, (4) Gesellschaft für Schwerionenforschung Darmstadt, Germany, (5) Warsaw University, Poland, (6) Yale University, New Haven, CT, USA, (7) University of Helsinki, Finland, (8) CEA, Saclay, France