Direct measurement of fission barrier heights of unstable heavy nuclei at ISOL facilities & ACTAR TPC

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Motivation

- Fission is expected to play a key role in the description of r-process in nucleosynthesis of n-rich nuclei in two neutron star merger.

- Fission barrier height is the parameter determining fission rate.

- Description of fission rate/fission barrier in induce fission is demanded in **NuPECC Long Range Plan 2017**.

- A very little progress was done up to present due to the methodology.
The Present Status

- Most of the known, directly measured, fission barriers heights ($B_f$) were obtained by more than 30 years ago.
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Part of the chart of the nuclides. Nuclei for which the fission barrier was determined experimentally are indicated by an asterisk. Dahlinger et al., 1982
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• The most of them from the nearest vicinity of the β stability line

“The Age of RIB” opens possibilities to measured Bf of exotic n-deficient nuclei in low energy fissions:
- βDF (even-even nuclei) – significant uncertainty in Bf!
- (d,pf) - (inverse kinematics) – New method for RIB!

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Physical background of fission barriers @ low $E^*$

Probability of low energy fission

$$ P_{LEf} = \frac{\int_0^{E_{\text{max}}} W(E^*) \frac{\Gamma_f(E^*)}{\Gamma_f(E^*) + \Gamma_\gamma(E^*)} dE^*}{\int_0^{E_{\text{max}}} W(E^*) dE^*} $$

- $W(E^*)$: Probability to populate a given excited state $\rightarrow$ Exp.
- $\Gamma_\gamma(E^*)$: Fission / $\gamma$ emission decay width, no other channel contributes $\rightarrow$ Exp./Th.

Fission decay width

$$ \Gamma_f(E^*) = \frac{1}{2\pi \rho_c(E^* - \Delta)} \int_0^{E^* - B_f - \Delta_{sp}} \rho_{sp}(E^* - B_f - \Delta_{sp} - E') dE' $$
Physical background of fission barriers @ low E*

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Probabilities of excitation of a given excited state \(\rightarrow \text{Exp.}\)

Fission / γ emission decay width, no other channel contributes \(\rightarrow \text{Exp./Th.}\)

Fission decay width

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Because of pairing energy \(\Delta_{sp}\) at the saddle point configuration of nucleus Bf could not be determined with good precision by present theory \(\rightarrow\) uncertainty for deduced Bf for others than odd-odd nuclei.

A small difference in Bf can caused a huge difference in \(P_{\text{LEf}}\)!!

**even-even, odd A:** \(\Delta_{sp} = \text{unnegligible and significant uncertainty - } \beta\text{DF, (d,pf)}\)

**odd-odd:** \(\Delta_{sp} = \text{zero contribution - (d,pf)}\)
(d, pf) & HIE-ISOLDE & ACTAR TPC

- ACTAR TPC enables to measure (d, pf) with post-accelerated n-deficient RIB in inverse kinematics

- ACTAR TPC offers higher fission rate and enables to obtain fission cross section for range of the energies \( \rightarrow \text{excitation function} \)

**Technique**

- the two fission fragments are detected in the forward-placed silicon array
- the proton from the transfer is either stopped in the volume or in Si-CsI telescope arrays surrounding the active volume

- \( E^*_RE \) from two body kinematics of proton vs. \( RE^* \)
  - ACTAR angle resolution < 1°/proton
  - uncertainty for \( E^*_RE \) < 0.5 MeV

- different position of (d, p) transfer in the ACTAR TPC corresponds to different \( E_{(beam)} \) of RIB (5 to 4.1 AMeV)
- fission excitation function for more than 60 points is possible
- multiple measured fission probabilities!!
(d,pf) & HIE-ISOLDE & ACTAR TPC

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**Bf determined with accuracy not achievable in another type of low-energy fission!**
&
**We proposed such experiment to INTC commission (HIE-ISOLDE)**
IS581 experiment

- The experiment for measurement of fission barrier heights of n-deficient odd-odd nuclei in (d,pf) was proposed to INTC in 2012
- IS581 experiment was approved by INTC commission in 2013
- IS581 was put in to the program of planned HIE-ISOLDE experiments
Experimental conditions of IS581 experiment

- the deuterium gas inside the active target (effective target thickness of 1.6 mg/cm², target chamber length parallel to beam of ~ 12.8 cm)
- the beam slows down from the initial energy of 5 AMeV to about 4.1 AMeV
- the reaction vertex can be reconstructed with a resolution better than 3 mm
  -> more than 60 points of the excitation function within the given energy range
- the beam intensity of $10^6$ pps
  -> **has to be optimized due to electrostatic mask along the beam of heavy nuclei!**
  -> a rate ranging from about 2 events/minute (at the highest energy) to 1 event/hour (at the lowest energy)

**Requested shifts:** 28 shifts (split into 2 runs over 2 years)
**Beamline:** 2nd REX beamline
Experiment approved as IS581 with all 28 shifts!
The period 2013 - 2017

- No progress until now – all experiments with ACTAR TPC demonstrator were focused on light ion beams

- There is a need to make the 1-sth measurement of IS581 with ACTAR TPC in 2018 -> longer shutdown of HIE-ISOLDE facilities

- **However, guarantee to get measurement time with ACTAR TPC is necessary!**

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Thank you for your attention!