β-decay study of neutron rich nuclei with the Total Absorption Spectroscopy method

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Outline

• Context and motivations for $\beta$ decay studies and TAS experiment

• Description of TAS method and analysis

• Experimental setup at Jyväskylä

• Preliminary results

• Conclusions and outlooks
Context

→ Nuclear structure
  - Neutron-skin
  - Pygmy Resonance
  - Deformation parameter
  - Equation of state of neutron matter

→ Astrophysical phenomena : r-process
  - Rapid neutron capture
  - Knowledge of capture/decay competition
  - Need for predictive microscopic models

→ Nuclear reactor
  - Decay heat :
    - Residual power (∼8% of nominal power)
    - Reactor safety
    - Predictive method = Summation of all the fission product contributions

- Antineutrino spectra :
  - Fuel monitoring for non-proliferation (ν flux depends on fuel composition)
  - Neutrino fundamental physics

Systematic discrepancies between measurements and calculations

Improve knowledge of beta-decay properties
Motivation: Why a TAS experiment?

→ The Pandemonium effect

- Weak point of the Ge detectors (mainly used for $\beta$-decay study)

  - Causes:
  - Very low geometrical and intrinsic efficiency

  - Consequences:
  - Overestimation of the feeding of the low energy levels

Solution: Total Absorption Spectroscopy

TAS method

→ A complementary approach

- **Germanium detectors**: **High resolution** single $\gamma$-ray detection
- **TAS detectors**: **High efficiency** + $4\pi = \text{Calorimeter}$ $\gamma$-ray cascade detection

- **Advantages**:
  - Almost 100% detection efficiency
  - Direct access to the $\beta$ intensity distribution $I_\beta$
  - Much less sensitive to the Pandemonium effect
- **Drawbacks**:
  - Deal with a complex analysis
  - Lower energy resolution than Ge detectors
  - Detailed knowledge of the daughter nucleus
Data analysis

- Aim of TAS analysis = β feeding

→ Solve the Inverse Problem

\[ d_i = \sum_j R_{ij} \cdot f_j \]

\( d_i \): Experimental data

\( R_{ij} \): Detector response matrix
- branching ratio matrix
- γ-response and β-response

\( f_j \): beta feeding

→ Requires clean spectrum

\(^{99}\text{Y} + \text{Contaminants}\)

\[ I_\beta = \frac{\sum f_\beta}{\sum f_k} \]

\[ S_\beta(E) = \frac{I_\beta(E)}{f(Z, Q_\beta - E) T_{1/2}} \]

Beta feeding  Beta Intensity

Solved by an iterative procedure based on the Bayes Theorem


Comparison with theoretical models
Experimental setup at Jyväskylä \(^{142}\text{Cs}, ^{99}\text{Y}, ^{138}\text{I}, ^{96,96m}\text{Y}\) 

- **DTAS** = 18 crystals of NaI(Tl) 
  - \(\sim 90\%\) total efficiency for a 1 MeV gamma 
  - \(\Delta E/E \sim 5\%\) at 1.3 MeV
- **\(\beta\) detector** = plastic detector 
  - In coincidence with \(\gamma\) \(\rightarrow\) suppression of the background 
  - 30\% detection efficiency 
- **HPGe detector** 
  - Allow identification of possible contaminants coming from the decay chain

Why Jyväskylä IGISOL-4 facility? 

→ Because of the JYFLTRAP, a double Penning Trap 
→ Mass resolution of \(\delta m/m \sim 10^{-6}\) 
→ A very pure beam is needed
Preliminary results for the $^{142}$Cs: Motivations

→ Nuclear structure

✓ Possible neutron-skin in the vicinity of the $^{132}$Sn
✓ Neutron orbital influence

→ Astrophysical phenomena: r-process

✓ Pygmy resonances
✓ $\beta$-decay: new probe below and above $S_n$
  (M. Scheck, PRL 116, 132501, 2016)

→ Nuclear reactor

✓ Priority 1 as contributor to antineutrino spectra
  + IAEA – INDC (NDS) 0676)

✓ Priority 3 as contributor to reactor decay heat
Preliminary results for the $^{142}$Cs

Difference between Input 1 and Input 2:

- $\gamma$-strength E1 and M1
  
  Generalized Lorentzian (GL) \[ (J. \text{ Kopecky and M. Uhl, Phys. Rev. C 41 (1990) 1941) \]
  
Preliminary results for the $^{142}$Cs

→ At low energy: lower value of β-feeding
Ground State feeding = 47%(Input 1) 44%(Input 2) 56%(ENSDF)

→ At high energy: continuous part beyond 3.5 MeV, missing in the ENSDF database

Only 3 values above 3.5 MeV in ENSDF

I$_y$ above S$_n$ study on-going

PANDEMONIUM EFFECT
Preliminary results for the $^{142}$Cs

Multiplicity study used to:
- verify/improve branching ratio matrix
- obtain a more detailed comparison between different sets of input parameters
- may constrain models

- D1M strength overestimate M1 above 1.5 MeV and underestimate it below
- Better reproduction with GL strength but needs improvement

Study ON-GOING
Conclusion and outlook

TAS experiment:
✓ An alternative method compared to High Resolution experiments...
✓ ... which gives additional data to complete nuclear databases, with a potential non-negligible impact on:
  ➤ Decay heat and $\bar{\nu}_e$ spectra calculations
  ➤ Constraints on model dedicated to calculate $T_{1/2}$, deformation and $P_n$ values
  ➤ Nuclear structure and r-process modeling

Current analysis:
$^{142}\text{Cs}$, $^{99}\text{Y}$, $^{138}\text{I}$, $^{96,96m}\text{Y}$

New feedings: nucleus affected by the Pandemonium effect

Result $\rightarrow I_\beta$  ➤ Calculate the beta strength to compare with theoretical models.

✓ Multiplicity study: may to use as a tool to constrain the different models
Thank you!

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