Beta Decay Spectroscopy at SPES

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Outline:
• Beta decay and n-rich nuclei
• decay station and ancillaries
• LOI presented
• β⁻ decay is the most common type of radioactive decay
  – β⁻ decay
  – β⁺ decay
  – Electron capture (EC)

  reasons to study beta decay:
  - Access to gross information on the decay, Half-life, Pn etc.
  - First information on excited states far from stability
  - Spin assignment owing to selection rules
  - Access to non-yrast states
  - Definition of shapes
  - Connection to mass measurements
  - Input for astrophysics and reactor heat calculation....
    ....many more...
* Changes in magic numbers

* Many new effects arising at small changes in nuclear configuration:
  - deformations
  - change in levels sequence
  - collectivity
  - isomerism and loss of isomerism
  - monopole drift
  - proton core excitations
  - proton intruder isomers
  ...

Shell model calculations need to include a large valence space to describe all effects

K.Sieja and F. Nowacki, PRC 81, 061303 R (2010)
Most of the heavy elements (Z > 30) are formed in neutron capture processes, either the slow (s) or rapid (r) process.
Masses:
• Sn location of the path
• $Q_\beta$, Sn theoretical $\beta$-decay properties, $n$-capture rates

Fission rates and distributions:
• $n$-induced
• spontaneous
• $\beta$-delayed

$\beta$-delayed $n$-emission branchings
(final abundances)

$\beta$-decay half-lives
(progenitor abundances, process speed)

$n$-capture rates
Smoothing progenitor abundances during freezeout

Seed production rates

ν-physics?

Nuclear physics in the $r$-process
The knowledge we have on nuclear structure and dynamics is based on about 3000 nuclei, whereas still more than 5000 new nuclei must exist. Almost all these new nuclei are expected to be neutron emitters, and hence, an understanding of this property and the involved technique becomes of pivotal importance for NS and future studies.

**Beta-delayed neutron emission**

- Practically all NEW nuclei, are expected to be neutron emitters!
Beta spectroscopy: true scenario

- $\beta$-transitions (mostly Gamow-Teller) are feeding highly excited states,

- these many, weak $\beta$-transitions are followed by the cascades of $\gamma$-transitions in the daughter nucleus,

- these weak $\gamma$-transitions are very difficult to detect with radiation detectors with low efficiency

- to determine a true $\beta$-feeding and resulting $\gamma$-decay patterns (nuclear structure),

- to determine a “decay heat” released by radioactive nuclei produced in nuclear fuels at power reactors,

*Total absorption $\gamma$-spectroscopy, TAS measurements*
Beta spectroscopy: experimental technique

Basic principle:
- Detect Mother nucleus implantation
- Correlate succeeding beta emission
  - measure HALF-LIFE ($T_{1/2}$)
  - measure delayed GAMMA EMISSION,
    spectroscopy of daughter nucleus

Tape system + Plastic/Si surrounded by HPGe + additional detectors
(LaBr3, Neutron det.) or Total Absorption Spectrometer

Moving tape system: long and short living radioactivity...2 possible measuring points
SPES beam intensities after the Ion Source (1+)

Calculated with MCNPX
Considered the release and ionization efficiency in agreement and re-scaled on HRIBF experimental values and currents (200μA/5μA)

BERTINI - ORNL
(FF cross sections)

SPES beams after Ion Source
- 10⁷-10⁹ pps
- 10⁶-10⁷ pps
- 10⁵-10⁶ pps
- 10⁴-10⁵ pps
- 10³-10⁴ pps
- 10 -10³ pps
- 0 -10 pps

https://web2.infn.it/spes/index.php CHARACTERISTICS/spes-beams-7037/spesbeamstable
New experimental halls

To be defined:
- Shielding
- Access to area
- LN2 lines
- Separation of different exp. areas

Courtesy of M. Comunian
In-house equipment

GASP coaxial HPGe det.  
With new AGATA-like electronics:
  - Preamplifiers  
  - digital sampling  
  - Preprocessing  
  - DAQ

Newly refurbished triple CLUSTER det.

Possible ancillary detectors:

* HPGe Clover/Cluster detectors  
* GALILEO coaxial detectors  
* Modified NEDA Neutron detectors  
  * TRACE Silicon detectors  
* Fast responding LaBr₃ det. For fast time measurements  
* Large volume LaBr₃/BaF₂ for TAS

200 μm thin dots: ~2 nA (10 V FD)  
1.5 mm thick dots: ~50–500 nA (200 V FD)
Activities already proposed via LOIs

C. Gross (ORNL, USA): **Nuclear Structure of neutron-rich nuclei determined through beta decay spectroscopy of fission fragments**

T. Kurtukian-Nieto (CENBG and University of Bordeaux, France): **Measurement of the decay characteristics of nuclei around A=90 relevant to r-process nucleosynthesis**

Gottardo (IPN, Orsay, France): **Neutron Decay Spectroscopy at SPES**

With contribution from:

B. Rubio (IFIC, Valencia, Spain): **Beta decay studies using the gamma Total Absorption Technique at present and future facilities: A personal point of view**
Overproduction of stable Sr, Y, and Zr in some UMP, compared to the SS r-process.

If a N = 56 “ladder” the β decay of $^{88}\text{Ge}$, $^{89}\text{As}$, and $^{90}\text{Se}$ would immediately translate into an enhanced production of Sr, Y, Zr.
* investigate the discrete states and the resonances above the neutron separation threshold in neutron-rich nuclei.
The states of interest will be populated by beta decay with a high Q value.

* population of collective resonant states at high excitation energy (>9 MeV).
The decays with sufficiently high Q values (> 10 MeV) could populate the Pygmy Dipole Resonance in selected physics cases, where the spin and parity of the mother nucleus do not disfavor the population of such states in the daughter nucleus.
The spin and parity of the decaying nucleus will also determine the component of the PDR which could be excited.
In some cases, there could be a direct excitation of ground-state dipole-excited modes (for example 1- states in even-even nuclei) of the daughter isotope, while in other cases a population of the PDR built on the isobaric analog state (IAS) is more favorable.

Tonnerre, VANDLE neutron arrays
\( \varepsilon: 12 \%; \sigma: 120 \text{ keV} \) (1 MeV)
TAS is an essential tool for precise measurements of beta-decay strength functions $B(GT)$.

The technique is well known and can be applied to any Isol facility provided isotopic and isobaric separation exists.

Experiments are proposed at the European Isol facilities (Jyväskylä, Isolde and ALTO).

LoI’s at Spiral II and RIKEN.

This workshop is timely and appropriated to study the opportunities at SPES.
Beams from SPES will be of high purity thanks to the 70 MeV production energy and the high resolution mass analysis. **These beams will enable a world class decay spectroscopy program and a collaboration with researchers from the former HRIBF can bring modern state-of-the-art detector systems for beta decay experiments and beam production techniques to SPES.** The exotic isotopes to be studied will impact r-process simulations, nuclear structure theory, and nuclear energy applications.
Conclusions:

Beta decay studies in exotic nuclei:
- A good tool to access first info on nuclei
- Strong correlation with nuclear astrophysics (nucleosynthesis)
- Long-assessed techniques to study gamma and neutron decay branches
- No need for post-acceleration
- Already identified suitable area and collaborations are being defined
- Try to use in-house equipment
- 3 LOI from external groups already submitted (without setup definition)
- Support from community
- Experimental areas to be defined, with possibility of other set-ups for egs. Mass measurements
- Commissioning with 5 μA proton current on UCx → authorization already got to operate.
- HRMS required for most cases. To define which can run without
Beta decay spectroscopy at SPES
1. Use of higher currents on different carbides → SiC & B_{4}C
2. A/q between 4 & 7 (Charge Breeder - RFQ - present ALPI Configuration) → upgrading foreseen as second priority depending on user requests
3. Accelerated beams currents safe values > 10^4 pps
4. All isotopes are easily obtained with PIS - but strong contamination which has to be evaluated for each requested ion → needs of experimental tagging
5. Cs and Rb are contaminants which are always present when using SIS and LIS. They can be eliminated by the Wien filter for isotopes far from their masses.
6. HRMS at present not in the budget → its employment is necessary in some cases (PIS source) but → reduction of RIB intensity → its use depend on specific request of user/experiment
7. Only few elements available at the beginning with LIS → need of development for each element → specific request to the target groups (Andrighetto)