Measurements of $\beta$-delayed neutron emission around the third r-process peak

ROGER CABALLERO-FOLCH (DFEN –UPC) & S410 experiment collaboration
Barcelona, 14 de juny de 2013
- Astrophysics motivation
- Experimental setup at GSI-FRS facility
- Detection System: SIMBA & BELEN detector
- Ongoing analysis and preliminary results
- Future measurements: BRIKEN
- Summary and outlook
Motivation: nucleosynthesis beyond Fe in the r-process path

Goal: Experimental determination of half lives and neutron branchings of several exotic nuclei in the neutron rich region beyond N=126

Understanding of A=195 peak in the r-process abundance pattern. R-process calculations rely on theoretical predictions (QRPA & FRDM), with remarkable discrepancies and large uncertainties.
Nuclear data for the Pt-peak formation: half-lives

N = 126

Known $t_{1/2}$

C. Domingo-Pardo Priv. Com.
Experiment at GSI – FRS facility. $^{238}\text{U}$ fragmentation beam.

Large intensity ($2 \times 10^9$ ions/pulse) & high-energy (1 GeV/u) for $^{238}\text{U}$ beams

Separation in flight

$Bp - \Delta E - Bp$

1.6 g/cm$^2$ Be Production target

SIMBA + BELEN

Tracking detectors: particle ID on an event-by-event basis.
SIMBA: Implats & $\beta$ decays
BELEN: Neutrons

The detection system is based on a stack of SSSD- and DSSD-detectors for measuring ion-implants and beta-decays (SIMBA). Implants-region was surrounded by the 4$n$ neutron detector BELEN.
The Beta dELayEd Neutron (BELEN) detector, based in $^3$He counters embedded in a polyethylene matrix, located around Silicon IMplantation Beta Absorber (SIMBA).
The detection of the neutron is based on an indirect method: the detection of the products of the reaction of the neutron with $^3$He counters:

$$^3\text{He} + n \rightarrow ^3\text{H} + ^1\text{H} + 765 \text{ keV}$$

Other reactions:

- $^{10}\text{B} + n \rightarrow ^7\text{Li}^* + ^4\text{He} + 2310 \text{ keV}$
- $^7\text{Li}^* \rightarrow ^7\text{Li} + 480 \text{ keV}$
Tests and experiments with BELEN detector

GSI: S410 “Measurement of $\beta$-delayed neutrons around the 3rd r-process peak” C. Domingo-Pardo et al.
PERFORMED, September 2011

GSI: S323 “Beta-decay of very neutron-rich Rh, Pd, Ag nuclei including the r-process waiting point $^{128}$Pd”. F. Montes et al.
PERFORMED, September 2011

Z=28, N=50; Z=50, N=82

JYFL (2009, 2010 & 2013)
I162 “Delayed neutron measurements for advanced reactor technologies and astrophysics” JL Tain JYFL. Expected 2013
B.Gomez-Hornillos et al. NIM in progress (2009 exp)

Background measurements at GSI (2010) and LSC Canfranc (2011)
Isomer tagging was used for Z identification and two centred settings on $^{211}\text{Hg}$ and $^{215}\text{Tl}$ were measured during 4.5 days. The implantation area was optimized for Hg and Tl region where good resolution has been obtained.
Good statistics implantation for $^{208-211}$Hg, $^{211-215}$Tl and $^{214-218}$Pb

Implantation pattern

Counts of implanted nuclei

Implants on the high segmented layers of SIMBA detector
Data available and data expected to obtain

Implanted in ROI with enough statistics:

\[ ^{208-211}\text{Hg}, \, ^{211-215}\text{Tl}, \, ^{214-218}\text{Pb} \]

Other implants of \[ ^{212-213}\text{Hg}, \, ^{216}\text{Tl}, \, ^{219}\text{Pb}, \, \text{and} \, ^{202-204}\text{Pt}, \]

\[ ^{203-208}\text{Au}, \, ^{217-221}\text{Bi} \]

Possible evaluation of more nuclei implanted implanted in other layers.

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PRELIMINARY results for half lives

209Hg

$T_{1/2} = 59.56 \text{ s (21.91)}$

$t_{1/2} = 36.5 (+/- 7.5) \text{ s}$

211Tl

$T_{1/2} = 73.49 \text{ s (30.25)}$

212Tl

$T_{1/2} = 75.00 \text{ s (33.51)}$

213Tl

$T_{1/2} = 58.30 \text{ s (29.35)}$

G. Benzoni et al. PLB 715 (2012)

t_{1/2} = 88 (+^{46}_{-29}) \text{ s}$

G. Benzoni et al. PLB 715 (2012)

t_{1/2} = 96 (+^{42}_{-38}) \text{ s}
Nuclear data for the Pt-peak formation: half-lives

How theoretical models compare with experiment?

- No experimental information along N=126 region nuclei
- Only possibility is to benchmark the performance of models in the neighbourhood

\[ N = 126 \]

→ It seems that nuclear models tend to overestimate the b-decay half-live at N<126 and to underestimate it for N>126...
PRELIMINARY neutron correlations

\[ P_n = \frac{1}{\epsilon_n} \frac{N_n \beta}{N \beta} \]

(Efficiency \(\sim 40\%\))
Nuclear data for the Pt-peak formation: b-neutrons

Beta-delayed neutron emission has a twofold impact in the nucleosynthesis:
- It enhances the neutron density of the environment after freeze-out (reactivation).
- It shifts the abundances towards lower masses (Pn: $A \to A-1$, P2n: $A \to A-2$, etc).

Only one experimental value is known: TI-210 !!

- G.Stetter, TID-14880(1961)

$Q_{\beta} - S_n > 0$
Future plans: improved detectors + larger RIB intensities

New campaign for the measurement of $\beta$-delayed neutrons at RIKEN:

Large need of $b$-delayed neutron emission measurements!!!

BRIKEN Campaign:
Opportunities with the BELEN neutron detector at RIKEN
Future plans: improved detectors + larger RIB intensities

2nd BRIKEN WORKSHOP: 30-31 July at RIKEN
Collaborators are welcome to join!!!
Summary and outlook

- Several species of neutron rich heavy nuclei have been produced and identified in the Hg/Tl/Pb region, beyond the shell closure N=126.

- Preliminary **half-lives** have been obtained by implant-beta correlation method with DSSD detectors. They must be rechecked with other numerical methods.

- In order to obtain final results, we need to improve several aspects in our data-analysis (simulation, statistical comparator, spatial correlations, time-correlations, etc).

- The analysis of **β-delayed neutron emission** probabilities is ongoing.

- We plan to measure a large amount of neutron-rich nuclei in a campaign at the RIB facility of RIKEN (Japan).
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