Experimental report

25/03/2019

Proposal: **3-17-10** **Council:** 4/2017

Title: Feeding of nanosecond isomers populated in the 176Lu(n,g) reaction

Research area: Nuclear and Particle Physics

This proposal is a new proposal

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Samples: 176Lu

Instrument	Requested days	Allocated days	From	To
FIPPS	7	7	03/04/2018	10/04/2018

Abstract:

The aim of the proposed experiment is to obtain a more complete nuclear level structure of 177Lu, especially at high excitation energy and paths to isomeric levels (with lifetimes from ns to µs). We want to use our pure target of 176Lu (99.995%) to avoid contamination from other capture reactions. The (n,g) reaction at thermal energy where the capture cross-section is around 2000 b will allow to obtain a good statistics. The use of the new FIPPS array combined with our LaBr3 array will allow us to get g-g-coincidences for g-g-spectroscopy analysis and to perform fast-timing to measure nuclear lifetimes greater than few hundreds ps. All these characteristics found only at ILL will make a unique opportunity to address our problem.

EXPERIMENTAL REPORT FOR PROPOSAL 3-17-10

ABSTRACT

The aim of the proposed experiment is to obtain a more complete nuclear level structure of ^{177}Lu, especially at high excitation energy and paths to isomeric levels (with lifetimes from ns to µs). We want to use our pure target of ^{176}Lu (99.995%) to avoid contamination from other capture reactions. The (n,γ) reaction at thermal energy where the capture cross-section is around 2000 b allow to obtain a good statistics. The use of the new FIPPS array combined with our $LaBr_3$ array allow us to get γ-γ-coincidences for γ-γ spectroscopy analysis and to perform fast-timing to measure nuclear lifetimes greater than few hundreds ps. All these characteristics found only at ILL make a unique opportunity to address our problem.

SCIENTIFIC BACKGROUND

Herein we propose to measure the gamma decay following the radiative capture on the Lu isotope, ^{176}Lu ($t_{1/2}$=3.76×10^{10} yr) and to infer the feeding of ns isomers of ^{177}Lu using the FIPPS instrument. This work benefits from measurements made in 2007 and in 2016 with DANCE at LANL on an isotope enriched target of ^{176}Lu [Den16] and the previous consequent measurement achieved at ILL in 1996 [Pet96]. Fundamental questions relevant to astrophysics, medical applications and to physics input to the statistical model will be tackled. Understanding isomer state production is of interest for studying astrophysical environments, such as neutron stars or supernovae where reactions on the isomeric states can occur [Kap03, Kaw09]. Carrier-added ^{177}Lu ($T_{1/2}$=6.65 d) used in nuclear medicine contains also a small amount of the long-lived 23/2- isomer ^{177m}Lu ($T_{1/2}$=160 d). With its long half-life this causes problems of waste water management in nuclear medicine departments [Hen09]. The path leading to this very high spin of 23/2- in ^{176}Lu(n,γ) reactions is not yet understood. Recently isomer yields in the ^{176}Lu(n,γ) reaction have been measured at DANCE [Den16]. These results, integrated over all neutron energies, have proved that the DANCE detector can be employed to measure isomeric ratios with a very good determination of the isomers lifetime and their gamma-ray decays from a Time-of-Flight experiment. This means that we are able to distinguish every gamma-cascade leading to the isomeric state and to follow the process from several specific resonances (well-known spin) or neutron energy bin to the isomeric state (well-known decay) at low neutron energy. These studies on the isomer feeding are amenable to new and valuable constraints for reaction models. These first results detailed in [Den16] were compared to several configurations of reaction models using the TALYS code [Kon07] to interpret them. Comparisons showed that the gamma-strength function used to describe the gamma decay should include a M1 resonance at 4 MeV which is an important confirmation of others results [Bec15] and a new way to improve considerably the prediction of reaction models [Ull13, Den16]. However, this new improvement of reaction models does not reach to reproduce the measured isomeric ratios. One of the explanations for that lies in the data table of discrete levels of ^{177}Lu which may be still incomplete or even false and does not give enough paths to feed short-lived isomeric levels.

Previous results In our work [Den16] we have shown that discrepancies were observed between theoretical and experimental results. These differences may come from an incomplete nuclear level structure of ^{177}Lu at high excitation energy as the figure 1a presents. The isomeric ratio measured on a neutron beam at LANL using the DANCE array is 10.5 % for the isomeric level at 761.7 keV. On the figure 1a, the only way to get calculated an isomeric ratio closer to the experimental one is to increase the number of levels taken into account into the model. But, at high excitation energy, we know that the nuclear level structure is still not well known and several levels are missing as the figure 1b shows.

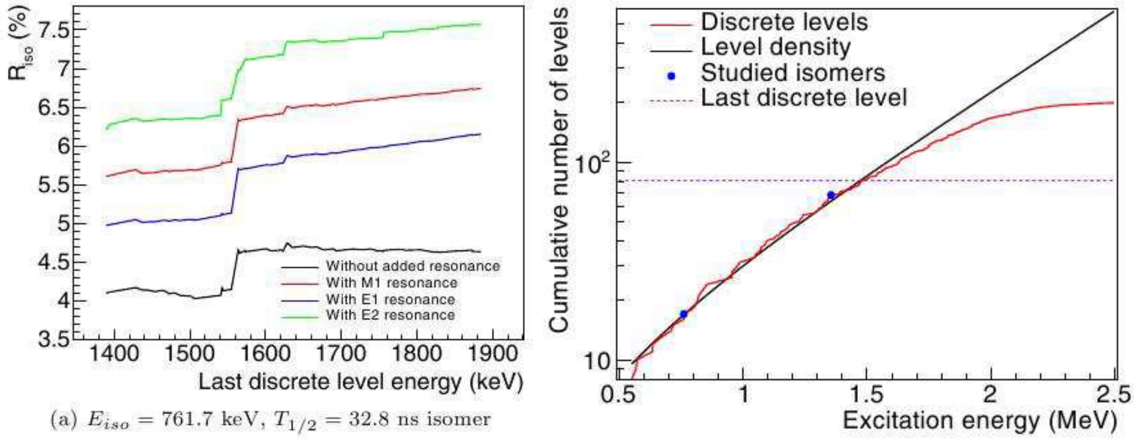

FIGURE 1 : (a) Isomeric ratio versus the last discrete level energy taken into account in the TALYS calculation. (b) Cumulative number of levels versus excitation energy: nuclear data and level density model.

The goal of this experiment 3-10-17 is to improve our knowledge of this nuclear level structure and to show that a complete nuclear level structure is really important to improve predictions of models for unstable nuclei. In the last measurement performed at ILL [Pet96] 1200 γ ray transitions had been measured at GAMS with a 27.1% enriched ^{176}Lu target. There of 310 had been assigned to ^{176}Lu(n,γ), but only 110 could be placed in the level scheme based on the Ritz principle and a coincidence setup of one BaF_2 detector and one Ge detector placed at an external neutron beam.

Now finally the experimental conditions for a much improved coincidence experiment had become available: the new performant FIPPS array is used to analyze $\gamma\gamma$ and $\gamma\gamma\gamma$ coincidences with HPGe resolution and angular correlation measurements for assignment of multipolarities. This is combined with valuable timing information from our 8 $LaBr_3$(Ce) detectors. Moreover we have used our pure target of ^{176}Lu (99.995%) to avoid contamination from other capture reactions. All this will allow to improve the ^{177}Lu level scheme to much higher excitation energies and to assign missing lifetimes.

SAMPLE AND BEAM-TIME USE

A unique ^{176}Lu target (see Figure 2), with an isotopic enrichment of nearly 99.995% for the mass of 0.542 ± 0.022 mg/cm2 and a deposit diameter of 7 mm on a 1 µm aluminized Mylar foil, was put into the beam tube of the ILL-FIPPS instrument.

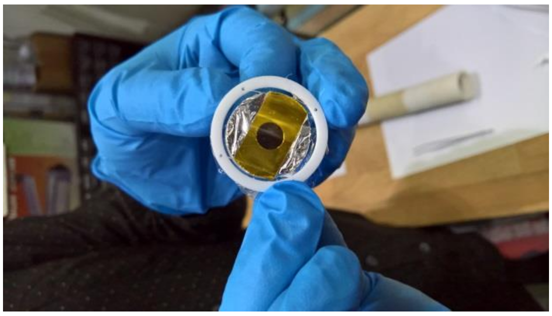

FIGURE 2 : The ^{176}Lu target set on the FIPSS target holder and then into the LiH tube shielding against scattering neutrons

With a capture cross section of 2000 b at thermal energy and a neutron flux of 9×10^7 n.cm-2.s-1 the capture rate has been at around 100 kHz. A preliminary analysis of the γ ray cascades using Ge-Ge-Ge coincidences for the completion of the level scheme shows that performance required for the study was largely reached.

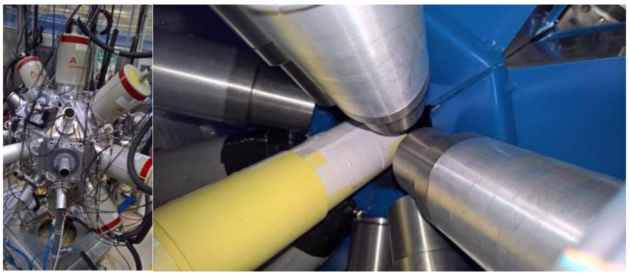

FIGURE 3 : The ILL FIPSS instrument with the beam tube in the center.

At this time, only preliminary results were extracted with a very good signal-to-background ratio as Fig. 3 shows. γ–γ coincidences can be achieved showing some clear decays of ^{177}Lu* formed in the neutron capture on ^{176}Lu. These preliminary results are in agreement with the reference level scheme of ^{177}Lu. Intensities would be carefully determined from these data.

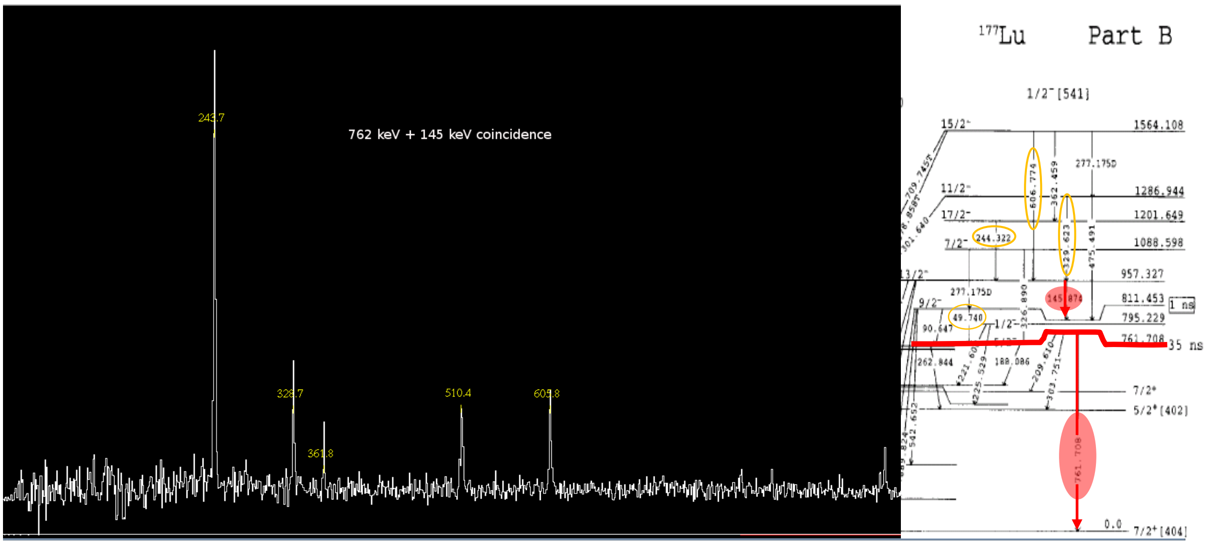

FIGURE 4 : Example of a γ–γ coincidence using the FIPPS instrument for this experiment ^{176}Lu(n,γ).

More coincidence could be studied to achieve a complete new study of the ^{177}Lu level scheme. A focus of the isomers feedings will be done (for example, feedings of the 35 ns isomer on Fig. 3). 140 hours of data corresponding to 3 To of data have to be interpreted.

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