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Results of fission products β decay properties measurement performed with a total absorption spectrometer

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Abstract. β-decay properties of fission products are very important for applied reactor physics, for instance to estimate the decay heat released immediately after the reactor shutdown and to estimate the $\bar{\nu}$ flux emitted. An accurate estimation of the decay heat and the $\bar{\nu}$ emitted flux from reactors, are necessary for purposes such as reactors operation safety and non-proliferation. In order to improve the precision in the prediction for these quantities, the bias due to the Pandemonium effect affecting some important fission product data has to be corrected. New measurements of fission products β-decay, not sensitive to this effect, have been performed with a Total Absorption Spectrometer (TAS) at the JYFL facility of Jyväskylä. An overview of the TAS technique and first results from the 2009 campaign will be presented.

1 Introduction

In nuclear reactors, fission products are mainly neutron-rich nuclei that essentially decay via the β^- process, some of them, emitting delayed neutrons. The β-decays of these nuclei are at the origin of reactor antineutrino emission as well as most of the decay heat production. In fundamental physics, studying β-decay properties helps constraining the β-strength function S_β which is of interest for nuclear structure, r-process nucleosynthesis and astrophysics.

At the shutdown of a reactor, the fission chain reaction induced by neutrons is broken. But the radiative power, maintained by the activity of fission fragments, remains and is sustained predominately

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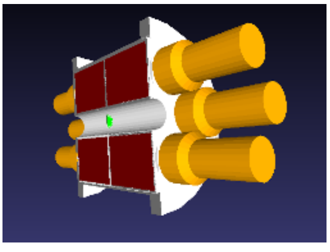
by the β-decays. This power representing ~7-8% of the nominal power of a reactor is called the *decay heat*. With the increasing amount of available decay data the most used and only predictive method for calculating the decay heat for future reactors design is the *summation method*. This method is based on the summation of the activity of all nuclei times the mean energy release during the decay. However, some calculations performed with the summation method by using different databases have shown some discrepancies in the estimation of reactor decay heat in comparison with reference integral decay heat measurements [1].

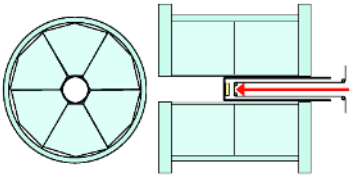
β-decay is also source of $\bar{\nu}_e$ in nuclear reactors. Studying $\bar{\nu}_e$ coming from reactors is very important for understanding ν physics, for instance for the determination of the θ_{13} parameter in the ν oscillation phenomenon [2–4]. The spectrum of $\bar{\nu}_e$ depends on the nuclear structure of the decaying nucleus. Thus the emitted $\bar{\nu}$ flux depends in norm and shape on the fuel composition of the reactor. Hence, $\bar{\nu}$ can be a useful tool for monitoring reactor core content for non proliferation. For these purposes a precise determination of $\bar{\nu}$ spectra is needed. The $\bar{\nu}$ spectrum of one fission product is the sum over the beta branches of all the $\bar{\nu}$ spectra of the parent nucleus to the daughter nucleus weighted by their respective branching ratio. The total $\bar{\nu}$ spectra is determined by summing over all fission product contributions.

2 The TAS Technique

β-decay properties are usually determined by measuring, with high resolution Ge crystals, the intensity and energy of γ-rays emitted after β transition of a parent nucleus to its daughter. In the case of large Q_β, or complex de-excitation pattern, it happens that some transitions are missed due to the low efficiency of Germanium detectors for high energy gammas or high multiplicity decay cascades. This leads to an overestimation of the high energy part of the β spectra and the $\bar{\nu}$ ones. This is called the Pandemonium effect [5]. Some of the data present in nuclear databases suffer from the distortion caused by this effect. This feature may explain the discrepancies observed by T. Yoshida et al. [1] and in $\bar{\nu}_e$ spectra calculations [6, 7]. A way to avoid the Pandemonium effect is to use a Total Absorption



(a) a GEANT4 picture from the 12BaF$_2$ TAS



(b) a sketch of the detector with a cross-section view and a longitudinal view showing the Si detector placed at the center and the magnetic tape

Figure 1: a 12 BaF$_2$ Total Absorption Spectrometer

Spectrometer (TAS), this detector is a 4π calorimeter constituted of one large or segmented crystals and with the particularity of having a γ cascade detection efficiency close to 100%. A TAS is directly sensitive to the β feeding, and for this reason represents a complementary tool for single γ peak detectors in order to solve the Pandemonium problem.

In [8], new measurements of β-decay have been done for 7 nuclei (^{105}Mo, ^{101}Nb and $^{102,104-107}$Tc) using a TAS. The data analysis has shown that 5 out of these nuclei suffer from the Pandemonium effect. The missing feedings have been corrected and a new calculation of the decay heat γ component is performed for ^{239}Pu almost solving the discrepancies observed by Yoshida et al. [1]. Recently, another study based on the same set of nuclei and corrected data has been done to study their impact on $\bar{\nu}_e$ spectra calculation using the summation method. The result of this analysis shows that Pandemonium nuclei are important cause of distortion of the shape of $\bar{\nu}_e$ energy spectra computed with the summation method, which motivates new measurements [6].

A Total Absorption Spectrometer has been developed by our collaborators of IFIC Valencia and the University of Surrey [9]. It is shown in figure 1 and consists of 12 BaF_2 optically independent crystals arranged in a cylindrical geometry of 25cm diameter and 25cm long. The total gamma real efficiency estimated for this setup is 80% at 5 MeV. A silicon detector is placed at the implantation point inside the TAS for tagging beta events. In 2009, an experiment has been performed with this spectrometer at the JYFL facility of Jyväskylä in Finland to take advantage of the IGISOL facility combined with the Penning traps allowing a high purity selectivity [10]. The detector has been calibrated with ^{137}Cs, ^{60}Co and ^{22,24}Na sources. During this experiment measurement of ^{92,93}Rb nuclei of interest for their contribution in reactors decay heat and $\bar{\nu}$ spectra calculations, have been performed. In the following section we will present preliminary results of the data analysis of ^{92}Rb.

3 Preliminary results

The observable in a β-decay TAS experiment is the β-feeding. To retrieve the β-feeding from the experimental data we need to unfold the *inverse problem*, which expresses the relation between the measured data and the real feeding distribution of the β-decay as stated in equation (1).

$$d_i = \sum_j R_{i,j} f_j \tag{1}$$

Where d_i is the measured data (cleaned of all possible contaminants) in the bin i, $R_{i,j}$ is the response matrix of the TAS, which holds the relation that makes a feeding in the bin j having a contribution in the bin i of data, and f_j is the real feeding to the level that corresponds to the bin j. The response matrix is obtained by using a GEANT4 simulation of the detector which is previously validated using calibration sources. The experimental data considered must be cleaned of any possible contaminants - pile-up, daughter activity, backgrounds, etc.

To solve the inverse problem, we use an *Expectation Maximization* algorithm based on *Bayes* conditional probability theorem and combined with a χ^2 minimisation [11]. As input we need a minimum knowledge about the nucleus we are studying like J^π information, γ-strength and level densities. The unknown part is then deduced step by step with a likelihood approach. It is also possible to put other constrains in the solving process like for example preventing feeding from forbidden transitions. One can appreciate the use of this process on the analysis of ^{92}Rb measured data in coincidence with the silicon detector presented in figure 2. The TAS spectrum in coincidence with the β events of the silicon detector (black curve) and a reconstructed spectrum (blue curve). This reconstructed spectrum is calculated from the feeding distribution obtained by solving the inverse problem and where the ground state β-feeding is fixed to 74%. This figure shows that we already have a quite good agreement between the reconstructed spectrum and the experimental one.

4 Conclusion

It has been shown that a significant part of the discrepancies observed in the calculation of reactor decay heat and the antineutrino spectra when using the summation method could be solved by using

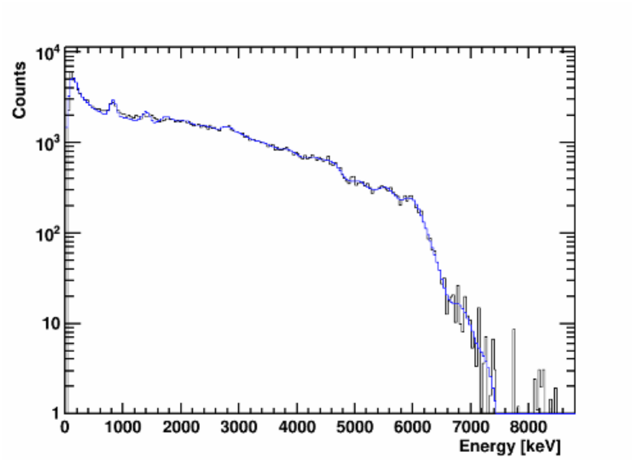


Figure 2: ^{92}Rb β tagged TAS spectrum (black), reconstructed spectrum (blue): Ground state feeding fixed at 74%.

a Total Absorption Spectroscopy measurement technique for β-decay properties, which has shown robustness against the Pandemonium effect. We have presented a very preliminary result from the ^{92}Rb which is of interest for reactor antineutrino spectra and decay heat calculations. The analysis is on-going and the impact of this nucleus on $\bar{\nu}$ spectra and decay heat will be shortly studied.

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