Probability of Th-229 isomer population in the alpha decay of U-233

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We use the NuDat database to calculate a lower bound to the probability of populating the Th-229 isomeric state in an alpha decay of U-233. Direct alpha decay into the isomer, gamma decay from higher-lying states, as well as internal conversion of higher-lying states are taken in to account. The result is 1.98%, in agreement with the 2% value often found in literature.

Many experiments that address the Th-229 isomer employ alpha decay of U-233 as a reliable source of Th-229m nuclei. The probability of isomer population is expected to be around 2%. This value is found all over the literature, however only rarely with a reference or supporting information. Those publications that do place a reference usually refer to references in other papers, which in turn refer either to early work at Idaho National Labs [1], or to Nuclear Data Sheets [2].

Here, we use the NuDat database [3] and extract all available information to quantify the various pathways that feed the isomer. Three feeding mechanism are considered: direct alpha decay into the isomer, as well as gamma decay and internal conversion (IC) from high-lying states. The latter two can proceed via cascades.

The energy of the isomer is expected to be of a few eV, while the energies of the gammas and IC electrons are on the order of ten keV. Current detectors for gammas/X-rays and electrons are not yet capable of resolving the doublet structure of the nuclear ground state. The same holds for detectors of alpha particles. This said, it is impossible to quantify the feeding of the isomer in U-233 alpha decay without further input. This additional input comes from calculated or estimated branching ratios for the gamma and IC de-excitation of higher-lying states. The NuDat database merges such models with real experimental data and lists hypothetical propabilities for the decay into the ground and isomeric state. As such, the probability calculated below depends directlly on the choice of branching ratios. The origin and validity of the assumed branching ratios cannot be traced [2].

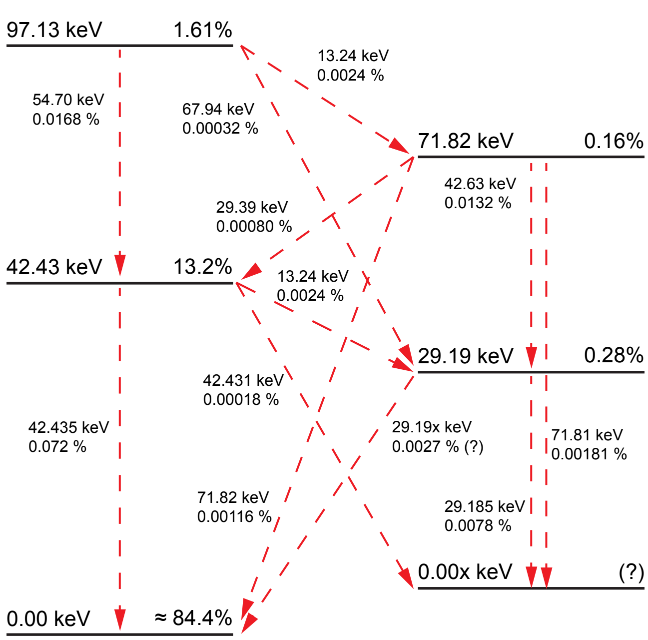

Figure 1: The first two bands in Th-229, showing their energies, and the population probability in U-233 alpha decay. Dashed lines represent gamma decay pathways.

parent	alpha decay	probability [%]
U-233	4824.2 keV	?

parent level	gamma decay	probability [%]
29.19 keV	29.185 keV	0.0078
42.43 keV	42.431 keV	0.00018
71.82 keV	71.812 keV	0.00181

parent level	shell	IC decay	probability [%]
29.19 keV	L	8.7130 keV	1.31
	M	24.0028 keV	0.33
	N_1	27.8556 keV	0.089
	N_2	28.0610 keV	0.0053
	O	29.0077 keV	0.020
	P	29.1664 keV	0.0037
42.32 keV	L	21.9589 keV	0.09
	M	37.2487 keV	0.025
	N_1	41.1015 keV	0.0066
	O	42.2540 keV	0.0015
	P	41.1015 keV	0.00024
71.82 keV	L	51.340 keV	0.071
	M	66.630 keV	0.0196
	N_1	70.482 keV	0.0052
	O	71.635 keV	0.00117
	P	71.793 keV	0.000193
		Sum	**1.98**

Table I: Population of the isomer through direct alpha decay of U-233, as well as from gamma decay, and internal conversion (IC) of higher-lying states; values taken from Ref. [3].

Figure 1 shows the five lowest states in Th-229 populated in the U-233 alpha decay. The resolution of alpha detectors is insufficient to resolve the ground-state doublet, and the probability of direct branching into the isomer is not given. Table I lists the probability of de-excitation of higher-lying states into the isomer via gamma emission, and via the IC channel.

In conclusion, we extract a value of $> 1.98\%$ for the population of the Th-299 isomer following alpha decay of U-233, in ecxellent agreement with the value of 2% often found in literature. It shall be stressed that this value is not a measured quantity, but constructed from assumptions or models regarding branching ratios, and may include substantial systematic uncertainties. A value of a few percent is compatible with the Munich experiment [4].

[1] L. A. Kroger and C. W. Reich, Nuclear Physics A **259**, 29 (1976).

[2] E. Browne and J. K. Tuli, Nuclear Data Sheets **109**, 2657 (2008).

[3] NuDat 2.6 database, http://www.nndc.bnl.gov/nudat2/.

[4] L. v. d. Wense *et al.*, Nature **533**, 47 (2016).