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# NUCLEAR STRUCTURE EFFECTS IN THE EXOTIC DECAY OF $^{225}$AC VIA $^{14}$C EMISSION

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## Summary

*We propose to build at Isolde a* $^{225}Ac$ *source by* $\beta$*-decay of* $^{225}$ *(Ra+Fr) beam, to be used at the superconducting spectrometer SOLENO of IPN - Orsay in order to study a possible fine structure in the spectrum of* $^{14}C$ *ions spontaneously emitted by* $^{225}Ac$.

## I - The Background

Exotic radioactivity, the rare process in which clusters in the mass range 14-32 are spontaneously emitted by heavy nuclei, did become an important chapter of nuclear physics, 8 years after its discovery. Thirteen cases of exotic emitters have been found among isotopes of Ra, Ac, Th, Pa, U, Pu. Branching ratios relative to $\alpha$ decay down to $10^{-16}$ have been measured with sophisticated techniques (1). From the theoretical point of view, unified theories taking into account exotic decay, $\alpha$ decay and, possibly, spontaneous fission within a common framework have been proposed. The role of exotic decay to investigate the structure of odd-A emitters has been established.

In december 1990 we produced 3 sources of $^{221}Fr$, $^{221}Ra$, and $^{225}Ac$ by the Fr+Ra beams of Isolde-2. In the case of $^{221}Fr$ and $^{221}Ra$, due to their short half lives we studied on-line the corresponding decays by means of nuclear track detectors in 4Π geometry. Analysis of detectors is in progress. The exotic decay of $^{225}Ac$ ($T_{1/2} = 10d$) was studied off-line. After a waiting time of 26 days, necessary both to let $^{225}Ac$ form from $\beta$ decay of $^{225}Ra$ and $^{225}Fr$, and to let possible $^{224}Ra$ contamination decay down, we sorrounded the source with an hemisphere of nuclear track detectors and performed the irradiation. Subsequent analysis made with an automatic image analyzer system revealed 305 $^{14}C$ events, 49 ± 19 of which are due to the decay of $^{221}Fr$, which is present in equilibrium in the $^{225}Ac$ source. The branching ratio relative to $\alpha$ decay is $(6.3 \pm 1.5)10^{-12}$.

It is this relatively high value, under estimated by all theoretical models by factors ranging between 6 and 30, that constitutes the main motivation of the present proposal.

It is known since many decades that $\alpha$ decays from odd-A emitters are hindered in respect to the neighbour even-even ones. The origin of this effect is the following.

When generalizing the many-body theory of $\alpha$ decay to heavy cluster emission (3), the cluster models take into account a spectroscopic factor, defined as the overlap integral between the wave functions of the initial and final systems.

In the case of light ($\alpha$) and heavy ($^{14}C$) cluster radioactivity, these hindered transitions have been interpreted as evidence for a particularly poor overlap, due to a change of state of the odd particle. This is indeed the situation which is most often found in g.s. → g.s. transitions for odd emitters, both in the case of $\alpha$ and $^{14}C$ decay. In the $^{223}Ra \rightarrow {}^{14}C + {}^{209}Pb$ decay indeed, the 11/2 + first excited state of $^{209}Pb$ has been found (4) to be preferentially populated, despite the fact that the penetrability for the g.s. transition is much longer. This surprising feature has been attributed to the fact that the Nilsson wave function describing the $^{223}$Ra g.s. contains large components arising from the i 11/2 neutron shell model orbit, the leading configuration of the last neutron in the $^{209}Pb$ first excited state.

The above arguments, which point out the importance of nuclear structure effects in exotic radioactivity, as it was found to be true for $\alpha$ radioactivity, can be used to interpret the relatively high probability of the decay $^{225}Ac \rightarrow {}^{14}C + {}^{211}Bi$.

Analysis of literature suggests that the similarity between the initial and final states which may give rise to a favoured transition could be met here for the g.s. → g.s. or, at worst, for the g.s. → $1^{st}$ excited state (E=404 KeV) transitions.

The first hypothesis is based on the assignment published in Ref. 5, according to which the g.s. configuration of $^{225}$Ac is 3/2 [532]. Such state originates from a h 9/2 proton state, i.e. the g.s. of $^{211}Bi$.

Therefore the transition for which the spectroscopic factor is maximized is the g.s. → g.s. one, a fact which would give to the decay the highest possible Q-value, and therefore a behaviour completely similar to that of even-even emitters.

The second hypothesis is based on more recent work $^{(6)}$ according to which the odd proton of $^{225}$Ac belongs to the $\Omega = 3/2$ orbit with $n_\Omega$=13 which originates mainly from the f 7/2 subshell; therefore the $1^{st}$ excited state of $^{211}Bi$ ($E^* = 404$ KeV, $J^\pi = 7/2^-$) should be favoured in the $^{14}C$ decay of $^{225}Ac$.

## II - The proposed experiment

The only possibility of testing the different hypothesis and to attain the spectroscopic factors is to measure the feeding of the low-lying levels of $^{211}Bi$, as was done for $^{223}Ra$.

This cannot be done, however, with the track detector technique as used in our previous experiment, due to the poor energy resolution. However, the use of the superconducting magnetic spectrometer SOLENO, which focalizes the $^{14}C$ ions on a high resolution Si(Au) detector, would permit to distinguish the different $^{14}C$ groups emitted by $^{225}$Ac to the ground state and to the first excited levels of $^{211}Bi$.

Let us recall that:

- the source and the detector are placed on the geometric axis of the spectrometer, with an obturator to exclude the view of the source by the detector.
- when the magnetic field is set to focus $^{14}C^{6+}$ or $^{14}C^{5+}$ ions on the detector, the $\alpha$ particles emitted by the source are focussed outside the detector. Moreover, the decay chain of $^{225}Ac$ does not contain radon isotope, which emanates from the source and diffuses up to the detector, where it generates a high alpha background, like in the case of $^{223}Ra$ or $^{222}Ra$ sources (7,8). So very intense source ( 1GBq) can be used without great difficulty. The source will be mounted in an aluminium holder, closed

by a 20 $\mu$g cm$^{-2}$ carbon foil at 3mm from the source, to avoid escape of recoiling atoms and to assure the equilibrium value of the $^{14}C$ ion charge state.
This will also allow to mantain the high quality of the source.

- the transmission of SOLENO is characterized by the solid angle $\Omega$ measured as the ratio of the $\alpha$ counting rate of the detector to the source strength. The use of a small diameter source, like those produced at Isolde, and a large detector (450 mm$^2$) permits to achieve a maximum $\Omega$ greater than 250 millisteradians.
- the energy resolution of the large Si(Au) detector, less than 150 KeV for 30 MeV $^{14}C$ ions, will be sufficient to distinguish between the $^{14}C$ group feeding the $^{211}$Bi ground state and those populating the first excited state, with an energy difference of 380 KeV.

To assure the success of the experiment, about 100 $^{14}C$ events must be registered, let us say in 15-20 day measurement, to observe $^{14}C$ groups of some percent intensity.

Let us consider a collection at ISOLDE of 100 mCi=3.7 × $10^9$ Bq of $^{225}Ra$. About 10 days after the end of production, the $^{225}Ac$ activity will be around 40 mCi = 1.5x $10^9$ Bq. and will stay approximatively constant over a period of 15 days (40 to 44 % of the initial activity of $^{225}Ra$).

With a ratio $^{14}C/\ \alpha = 6.3 \times 10^{-12}$, such a source emits:

$$1.5.10^9 \times 6.3 \times 10^{-12} \times 86400 = 815 ^{14}C \text{ per day in } 4\pi$$

Now with a solid angle of detection = 0.25 steradian and a 35% probability for the $^{14}C^{5+}$ charge state, we will detect:

$$815 \times 0.35 \times 0.25/4\pi = 5.7\ ^{14}C \text{ per day, so approximatively } 100\ ^{14}C \text{ in } 15 - 20 \text{ days.}$$

Such an intensity is about one order of magnitude higher than the one we obtained in 1990, by using a $^{225}$(Fr+Ra) beam of 2× $10^9$ atoms /sec for 66.6 hours. We therefore require now a beam of the order of $10^{10}$ atoms/sec for about 8 shifts.

With the above intensity it should also be possible to have, as an extra bonus, an independent measurement of the $^{14}C$ decay of $^{221}$Fr, always in equilibrium with $^{225}$Ac.

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