EXPERIMENTAL STUDIES ON EXOTIC DECAY -
A SHORT REVIEW

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CHAPTER 3

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3.1 Experimental techniques

Rose and Jones [3] in their famous experiment using ΔE-E surface barrier silicon detectors were able to detect a few carbon events within α particle background about $10^9$ times higher. They used relatively weak $^{227}$Ac source containing $^{223}$Ra in secular equilibrium. Gales et al [46] in their experiment used a super conducting magnetic solenoid spectrometer to suppress the intense α background. This allowed them to use intense $^{227}$Ac source 60 times stronger than the one used by Rose and Jones. Kutschera et al [47] used an Enge split pole magnetic spectrograph to suppress the intense α radiation and to identify $^{14}$C particle. The spectrograph was calibrated with tandem accelerated beam of $^{14}$C, $^{13}$C and $^{12}$C.

To suppress α particle background and to increase the overall detection efficiency, solid-state nuclear track detectors (SSNTD) are now widely used which is the most sensitive technique to detect the rare decay mode, the exotic decay. Price et al [48] demonstrated that polycarbonate track detecting foils like Rodyne-P are well-suited detectors for the study of $^{14}$C emission radioactivity even for $^{14}$C/α branching ratio below
The energy of the fragments recorded was determined via a calibrated range energy relation [49]. It is also possible to identify the nuclear charge $Z$ by observing the ratio of etching rate along the track to the general etching rate $V_f/V_g$ as function of the residual range [50]. The branching ratio of cluster emission with respect to alpha decay, $B$ can be calculated as [51]

$$\rho_{\text{cluster}}(> R_{\min}) = j_a(> E_{\min}) A t \Omega 4\pi B / \eta$$

where $\rho_{\text{cluster}}(> R_{\min})$ is the density of track formed by the cluster, $j_a(> E_{\min})$ is the alpha intensity, $A$ is the source area, $t$ is the exposure time, $\Omega$ is the solid angle and $\eta$ is the detection efficiency.

Using similar plastic track detectors Barwick et al [52] detected $^{24}\text{Ne}$ emission from $^{232}\text{U}$. In later experiments plastic detectors are replaced by phosphate glass detectors, which have better discrimination against $\alpha$ particle. This led to the detection of $^{20}\text{O}$, $^{23}\text{F}$, $^{30}\text{Mg}$, and $^{32,34}\text{Si}$ in addition to $^{24,26}\text{Ne}$. Phosphate glass BPI is more sensitive to $^{14}\text{C}$, for Ne and Mg better choice would be PSK50 and for Si, LG750 glass would be more sensitive. Phosphate glass detectors are ideally suited for the detection of both heavy clusters and spontaneous fission tracks. It has now become possible to measure in the same experiment the spontaneous fission probability simultaneously with exotic decay probability [53,54].
SSNTDs are not suited for fine structure experiments where better energy resolution is required. Brillard et al [55] and Hussonnois et al [56] in their fine structure experiment used magnetic spectrometer SOLENO to focus emitted $^{14}$C clusters on a single Si detector. This resulted in a high quality energy spectrum.

The decaying parent nuclei may either be a member of natural radioactive series or produced artificially (on line or off line production). $^{14}$C from $^{222}$Ra, $^{18}$O from $^{230}$U, $^{34}$Si from $^{242}$Cm are examples for off line production while $^{14}$C from $^{221}$Ra, $^{221}$Fr, $^{223}$Ra, $^{225}$Ac performed at Isolde and $^{12}$C decay of $^{114}$Ba at GSI (Germany) are examples for on line production [57].

### 3.2 Experimentally observed decay modes

Altogether about 24 modes of exotic decay from 18 parent nuclei emitting clusters ranging from carbon to silicon have so far been confirmed and reported in the literature. The upper limit for decay rate for 16 modes were measured and one case of fine structure in the energy spectrum of $^{14}$C clusters from $^{223}$Ra was found. The heaviest cluster so far measured is $^{34}$Si [58,59,60]. $^{14}$C is the only cluster for which quite a few cases from both odd and even parent have been measured. $^{23}$F is the only example for odd A cluster measured with single event using an array of 375 cm$^2$ of BPI plates in 2π geometry by Berkely –Livermore-Milano collaboration [61]. As for the multiple branching ratio, so far only three nuclei ($^{231}$Pa, $^{234}$U and $^{238}$Pu) are found to decay with the emission of two
heavy clusters other than $\alpha$ particle [53,61,62] but none with more than two.$^{234}$U was the first nuclide for which 4 hadronic decay modes ($\alpha$, Ne, Mg and spontaneous fission) have been measured [63,64].$^{238}$Pu was the other nuclei for which 4 hadronic decay modes ($\alpha$, Mg, Si and spontaneous fission) have been measured [62].