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Beta-Delayed Proton Precursors with $59 \leq Z \leq 62$

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Abstract:
The new, beta-delayed proton emitters $^{128}Pr(3.2^{+0.5}_{-0.4}$ s), $^{130}Pm(2.2^{+0.6}_{-0.4}$ s), and $^{132}Pm(5.0^{+0.8}_{-0.6}$ s) have been observed at the on-line isotope separator OASIS. Also studied were ^{129}Nd and ^{133}Sm.

Our on-going study of the decay properties of very neutron-deficient lanthanides has led to detailed information about beta-delayed proton emitters with $59 \leq Z \leq 62$. The isotopes were produced at the SuperHILAC's on-line isotope separator OASIS [1] in reactions of ^{40}Ca projectiles on ^{92}Mo and ^{96}Ru targets enriched to >95%. Decay studies were carried out in a low background spectroscopy laboratory. The isotope of interest was passed through a slit in the focal plane of the mass separator, transported ionoptically to a fast cycling tape, and periodically positioned between a silicon charged particle telescope, a HPGe x-ray detector, and a GAMMA-X Ge detector. Decays involving beta-delayed gamma rays and protons along with any coincident positrons, x-rays and gamma rays were measured event-by-event and written to computer tape for subsequent replay and analysis.

The preliminary results of our recent work are summarized in Tables 1 and 2.

<u>A=128</u>: In a previous experiment a delayed proton activity was observed at this mass number with a half-life of 4 ± 2 s [2]. This activity was <u>incorrectly</u> assigned to ^{128}Nd on the basis of cross-section and half-life predictions. We repeated this measurement to detect the characteristic x-rays associated with electron capture delayed proton emission which provide an unambiguous Z identification. A weak beta-delayed proton activity with a half-life of $3.2^{+0.5}_{-0.4}$ s observed in coincidence with Ce K x-rays can now be unambiguously assigned to the new isotope ^{128}Pr. No evidence for beta-delayed proton decay from ^{128}Nd was observed. ^{128}Pr was also identified by its beta decay to the known rotational levels in ^{128}Ce. The decay analysis of the gamma rays from the de-excitation of the 2+ and 4+ levels in ^{128}Ce yields a half-life of 3.0 ± 0.1 s in good agreement with the proton half-life, but considerably shorter than the value of 9 s predicted by the gross theory of beta decay [3].

<u>A=129</u>: A β-delayed proton activity with a half-life of 5.9 ± 0.6 s at this mass was assigned to ^{129}Nd by Bogdanov et al. [4] based on systematics for delayed proton emission. We decided to confirm this result since the high cross section for production of this isotope enabled a thorough study of its decay properties. A strong β-delayed proton activity was indeed observed and a more precise half-life of 4.9 ± 0.2 s was determined. Electron capture decay to proton unbound levels in ^{129}Pr gave rise to characteristic Pr K x-rays in coincidence with protons which confirms the assignment of ^{129}Nd. A strong feeding to the known 2+ level of ^{128}Ce was observed via a prominent gamma ray at 207.3 keV in coincidence with the protons. A comparison of the proton branches to the ground and first two excited states in ^{128}Ce with statistical model calculations indicates that a ground state spin of 5/2+ as predicted by Seeger and Howard [5] for ^{129}Nd is compatible with the experiment. The statistical model results do not allow an unambiguous parity assignment in this case.

<u>A=130</u>: A weak β-delayed proton activity with a half-life of $2.2^{+0.6}_{-0.4}$ s was observed at this mass. The Nd K x-rays measured in coincidence with the protons assign the activity to the new isotope ^{130}Pm. This is the first observation of proton emission from a promethium precursor. The measured half-life agrees well with the predicted value of 2 s [3].

<u>A=132</u>: ^{132}Pm with a half-life of 4 ± 2 s was previously identified by decay analysis of the Nd x-rays associated with electron capture [4]. No delayed proton branch was reported. A weak delayed proton branch was expected on the basis of the 5.6 MeV $Q_{EC}-S_p$ value, and the fact that the N = 71 isotones, ^{131}Nd ($Q_{EC}-S_p$ = 4.3 MeV) and ^{133}Sm ($Q_{EC}-S_p$ = 7.1 MeV), were known delayed proton emitters. Delayed

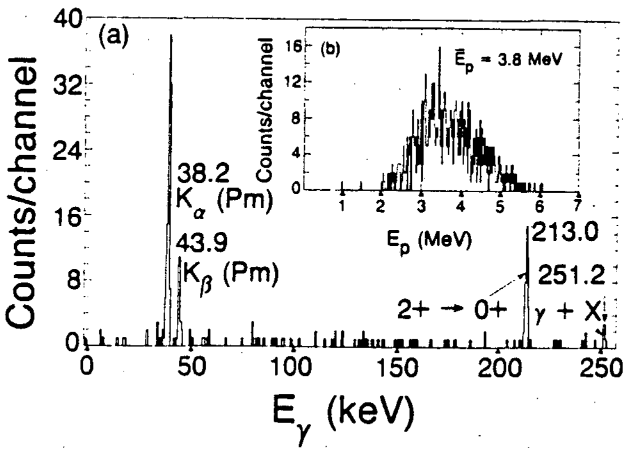

Fig. 1: Low energy photons (a.) in coincidence with beta-delayed protons (b.) from ^{133}Sm.

protons with a half-life of $5.0^{+0.8}_{-0.6}$ s were observed and assigned to ^{132}Pm on the basis of the Nd K x-rays in coincidence with the protons.

A=133: A β-delayed proton activity with a half-life of 3.2 ± 0.4 s was assigned to ^{133}Sm by Bogdanov et al. [4] based on systematics for delayed proton emission. We observed a strong delayed proton activity in coincidence with Pm K x-rays (fig. 1) confirming this activity as ^{133}Sm. Our half-life value of 2.8 ± 0.2 s is in reasonable agreement with the above result. A strong feeding of the lowest 2+ level in ^{132}Nd was observed in coincidence with the protons. This is the first observation of the 2+ level in ^{132}Nd. Its energy of 213.0 keV agrees well with the value expected from the systematics for this region (fig. 2). The predicted ground state spin for ^{133}Sm is 5/2+ [5]. Statistical model calculations indicate that this would result in a 12% proton decay branch to the 4+ level in ^{132}Nd. The expected 4+ to 2+ gamma transition was, however, not observed in the experiment and the question of the ground state spin and parity of ^{133}Sm, therefore, remains presently unresolved.

TABLE 1: E_{LAB} = bombarding energy; $T_{1/2}$,exp = measured half-life of the precursor; and $T_{1/2}$,g.t. = half-life of the precursor predicted from the gross theory of beta decay [3].

TABLE 1.

Isotope	Reaction	E_{LAB} (MeV)	$T_{1/2}$,exp. (s)	$T_{1/2}$,g.t. (s)
^{128}Pr	^{92}Mo(^{40}Ca,3pn)	170	$3.2^{+0.5}_{-0.4}$	9
^{129}Nd	^{92}Mo(^{40}Ca,2pn)	170	4.9±0.2	7
^{130}Pm	^{92}Mo(^{40}Ca,pn)	170	$2.2^{+0.6}_{-0.4}$	2
^{132}Pm	^{96}Ru(^{40}Ca,3pn)	175	$5.0^{+0.8}_{-0.6}$	5
^{133}Sm	^{96}Ru(^{40}Ca,2pn)	175	2.8±0.2	4

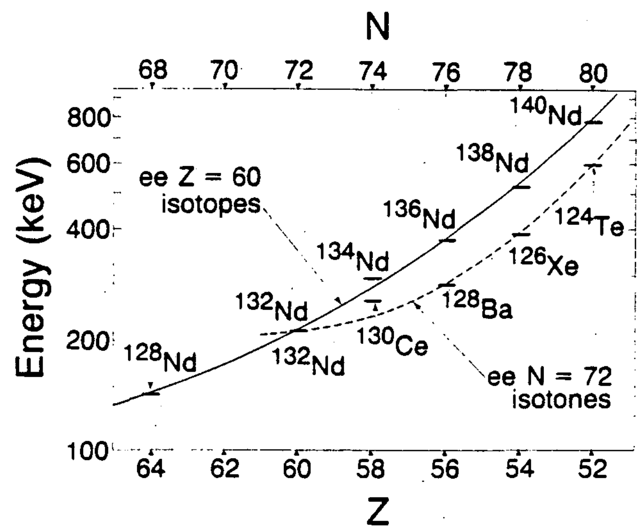

Fig. 2: Systematics for the lowest energy 2+ levels in ee Nd isotopes and ee N=72 isotones, including the latest result for ^{132}Nd. (In a recent experiment where we synthesized ^{131}Sm we have found evidence for the lowest 2+ level in ^{130}Nd at 159 keV.)

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TABLE 2: E_p,ave = average energy of the delayed protons; E_p,range = energy range of the delayed protons; $\bar{K}_\alpha,\bar{K}_\beta$ = the average K_α and K_β x-ray energies observed in coincidence with delayed protons; and GAMMA = principal gamma lines observed in coincidence with protons.

TABLE 2.

Isotope	E_p,ave. (MeV)	E_p,range (MeV)	$\bar{K}_\alpha,\bar{K}_\beta$	GAMMA (keV)
^{128}Pr	3.2	1.9-5.0	34.5,38.6	---
^{129}Nd	3.7	1.8-5.6	35.5,40.9	207,400
^{130}Pm	3.9	2.1-5.8	36.7,42.3	---
^{132}Pm	3.6	2.2-5.0	36.7,42.0	---
^{133}Sm	3.8	2.0-6.0	38.2,43.9	213.0

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