Description

Name of spokesperson (Collaboration/Lab):Gopal Mukherjee

Title: **Study of β-decay and β-delayed proton emission in neutron deficient isotopes of Cd and In (Z = 48, 49)**

Abstract: In this Letter of Intent we would like to study the beta-decay and beta-delayed proton emission in Cd (Z = 48, N = 49,50,51) and In (Z = 49, N = 52,53) isotopes. The measurements include the decay gamma rays by both high resolution spectroscopy (HRS) and total absorption spectroscopy (TAS). With these measurements, the properties of the excited states in the daughter and the beta-feeding intensities will be established. We will also determine the branching ratio of the beta-delayed proton emission, whereever applicable. In the long run, the halflife measurement of the excited daughter states will also be attempted by fast timing technique taking advantage of the use of $LaBr_3$(Ce) detectors. These measurements will provide crucial information on the shell structure for the neutron-deficient nuclei around the doubly magic ^{100}Sn and will provide useful inputs to the astrophysical process for the production and abundance of proton-rich nuclei, in particular above the ^{96}Cd waiting point nucleus. This proposed study encompasses both sides of the N = 50 shell closure to get a comprehensive picture of the decay modes around neutron shell closure close to ^{100}Sn. The produced nuclei (using, parimarily, heavy-ion induced fusion evaporation reaction), following Z and A separation, will be implanted on a magnetic tape and transported to the decay station composed of a powerful spectrometer developed by $(NA)^2$STARS collaboration. This detection system include a combined TAS array consisting of LaBr3(Ce), NaI(Tl) and BaF_2 detectors. This will also include a few HPGe detectors and beta detector to facilitate the HRS measurement, X-ray measurement and charged particle detection.

The goal of the experiment will be fully achieved through a series of measurements with increasing complexity in terms of nucleus being studied and the detection system being used.

Requested beam availability in...	☒ 1-3 years	☐ 3-5 years	☐ 5-10 years

Beam (ion, energy, intensity, number of UTs – 1UT=8h) : 21

$^{A}_{Z}X^{1+}$	50Cr	Energy	~ 4 MeV/A
		Intensity	3-5x10^13 pps
Bunched beam (yes/no) No		Freg / Length	Hz / µs
Purity	%	Estimated UT nb	

Production site:

SPIRAL1	S3-LEB
	√

Instruments to be used (please add instrument name if missing) :

MORA	LUMIERE	TAS	PIPERADE	MLLTRAP	OTHER
		√			

Other information (cooled / bunched beam, continuous beam / tape drive system / other request…) :

Study of β-decay and β-delayed proton emission in neutron deficient isotopes of Cd and In (Z = 48, 49)

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S. Nandi et al. : UGC-DAE-CSR, Kolkata, India
J.C. Thomas et al : GANIL, France
M. Fallot et al. : Subatech, France
And Others

Abstract: : In this Letter of Intent we would like to study the beta-decay and beta-delayed proton emission in ^{97,98,99}Cd (Z = 48, N = 49,50,51) and ^{101,103}In (Z = 49, N = 52,53) isotopes. The measurements include the decay gamma rays by both high resolution spectroscopy (HRS) and total absorption spectroscopy (TAS). With these measurements, the properties of the excited states in the daughter and the beta-feeding intensities will be established. We will also determine the branching ratio of the beta-delayed proton emission, whereever applicable. In the long run, the halflife measurement of the excited daughter states will also be attempted by fast timing technique taking advantage of the use of $LaBr_3$(Ce) detectors. These measurements will provide crucial information on the shell structure for the neutron-deficient nuclei around the doubly magic ^{100}Sn and will provide useful inputs to the astrophysical process for the production and abundance of proton-rich nuclei, in particular above the ^{96}Cd waiting point nucleus. This proposed study encompasses both sides of the N = 50 shell closure to get a comprehensive picture of the decay modes around neutron shell closure close to ^{100}Sn. The produced nuclei (using, parimarily, heavy-ion induced fusion evaporation reaction), following Z and A separation, will be implanted on a magnetic tape and transported to the decay station composed of a powerful spectrometer developed by $(NA)^2$STARS collaboration. This detection system include a combined TAS

array consisting of LaBr3(Ce), NaI(Tl) and BaF_2 detectors. This will also include a few HPGe detectors and beta detector to facilitate the HRS measurement, X-ray measurement and charged particle detection.

The goal of the experiment will be fully achieved through a series of measurements with increasing complexity in terms of nucleus being studied and the detection system being used.

Scientific motivations

Among the exotic nuclei in the neutron deficient side of the nuclear chart, ^{100}Sn has drawn a lot of attention, mostly due to its crucial status as one of the heaviest self-conjugate, doubly-magic, particle-stable nucleus with strong p-n interaction in the $g_{9/2}$ orbit. In order to understand the shell structure and the features of the shell evolution towards proton drip line vis-à-vis the contribution and effect of the proton-neutron pairing in the $g_{9/2}$ orbital to stabilize the nuclear matter against proton decay and thereby, the robustness of the N = Z = 50 core, it is essential to experimentally investigate the decay of nuclei around ^{100}Sn [1-3]. The proton single particle states near ^{100}Sn can be identified from the decay of In and Cd isotopes in this region. The nuclei near the proton drip line, such as the ones of our interest, have large decay Q value (8-10 MeV), which is much higher than the one proton separation energies (<~ 2 MeV) of their beta-decay daughters. Therefore, these proton-rich nuclei are also prone to undergo β-delayed proton emission. This has important implication in both nuclear physics and nuclear astrophysics. The nuclei near the ^{100}Sn region are of particular importance as they lie in a region towards the end of the rapid proton capture process path [4]. The neutron deficient isotopes of In (Z = 49) and Cd (Z = 48), with one and two proton holes in the $g_{9/2}$ orbital, are the important nuclei to study in this direction. The proton $g_{9/2}$ orbital below Z = 50 and neutron $g_{7/2}$ orbital above N = 50 facilitate the superallowed Gammow Teller (GT) beta decay in these nuclei. However, it has been found that there is a large mismatch between the calculated GT strength function of B(GT) = 17.78 [5] obtained from extreme single particle model [6] and the experimental value of 9.1 (+3.0, -2.6) [7]. The so-called GT quenching depends on several factors including a particle-hole excitation and configuration mixing, that raises a question on the robustness of the N = Z = 50 shell closure. Moreover, the variation of B(GT) values for the nuclei in this region can be an indicator of the evolution of shell structure of the nuclei in the proton-rich side of the nuclear chart around ^{100}Sn.

One of the most comprehensive recent β and βp decay spectroscopy experiments in this mass region was performed at RIKEN by J. Park et al. [8]. In this experiment, the gamma rays following β and βp decays were measured for several N <52 nuclei from Z = 43 to 50 and the excited states in these nuclei were identified. The $T_{1/2}$ and βp branchings were also measured. Branching ratio for βp ground-state decay in ^{96}Cd was found to be 1.7(4)% while for the odd-A ^{97}Cd it was measured as 7.4(2)%. The decay of ^{98}Cd was not measured in this work. A limit of βp < 0.025% was estimated for ^{98}Cd, way back in 1996 [9] from an experiment performed at GSI UNILAC.

The βp branching of Cd isotopes, taken from Ref. [10], along with other relevant quantities are given in Table-1. It is seen that there is substantial delayed proton branching in ^{97}Cd compared to ^{98}Cd. In particular, a large branching is obtained for the isomeric state decay. However, in case of ^{98}Cd, the βp branching is not well known, but the limit suggest that it is about two orders of magnitude less than that in ^{97}Cd. In case of ^{99}Cd with one neutron hole in $g_{9/2}$, the βp branching is at least an order of magnitude more than that in ^{98}Cd. These indicate a much stable configuration in semi-magic ^{98}Cd suggestive of a robust core configuration towards ^{100}Sn.

Table 1: βp branching of Cd isotopes.

Parent	$T_{1/2}$	Q(β) (keV)	β-decay daughter	Q(βp) (keV	Sp (keV)	βp decay daughter	βp branching (%)
^{95}Cd	32 (3) ms	12970	^{95}Ag	12180	800	^{94}Pd	4.5 (+12, -10)
^{96}Cd	1.02(6) s	8900	^{96}Ag	7100	4346(5)	^{95}Pd	1.7(4)
^{96m}Cd (16^+)	0.53(3) s						15.49(21)
^{97}Cd	1.16(85) s	10200	^{97}Ag	8200	1930	^{96}Ag	7.4(2)
^{97m}Cd ($25/2^+$)	3.86(6) s						25.1(5)
^{98}Cd	9.3(1) s	5430	^{98}Ag	2880	4100	^{97}Pd	<0.029
^{98m}Cd (12^+)	224 ns						?
^{99}Cd	17(1) s	6781	^{99}Ag	4101	2680	^{98}Pd	0.21(2)

A more precise value of βp branching in ^{98}Cd will be useful for estimating a more precise production rate of the Mo and Ru nuclei around A = 92 – 98, the transition point nuclei in the rp- and γ-process in the synthesis of nuclei near the proton drip line. Moreover, the β-decays of the ^{97,98,99}Cd nuclei are not well studied. The incompleteness of the decay schemes is quite evident from the large difference of decay Q value with the excitation energy of the highest energy level identified in the decay scheme. For example, the decay scheme of ^{99}Cd is known up to the 1.32 MeV of excitation in ^{99}Ag though the decay Q-value is about 6.78 MeV. Moreover, the feeding intensities in this decay are also not known. Therefore, it is important to get a more complete decay schemes of these nuclei.

In case of Indium isotopes, the β-decay of ^{102,103}In has been studied in detail by using both HRS and TAS [11,12,13]. Large disagreement in the GT strength function has been found in the two measurements, underlying the importance of determining the complete GT strength in TAS measurements. However, the decay of ^{101}In were not well studied. Only one state at 252.3 keV was established in the daughter ^{101}Cd from the decay of ^{101}In, other 3 observed gamma rays could not be placed in the level scheme [14]. However, the decay scheme seems to be highly incomplete as several gamma rays are tentatively placed and the spin and parities of most of the states in the daughter are either not determined or tentatively assigned. Also, the Q-value of the decay is ~ 6.1 MeV while the daughter states are known only up to 3.8 MeV. Therefore, it is important to study the decay of these nuclei using both TAS and HRS.

Experimental technique

The high-performance total absorption spectrometer system developed by the $(NA)^2$STARS collaboration [15] consists of a new ring of sixteen LaBr 3:Ce detectors (STARS), which can be coupled to two advanced modular TAS arrays: DTAS, composed of eighteen NaI(Tl) modules, and Rocinante, built from twelve BaF_2 modules. The nuclei will be implanted on a magnetic tape at the center of the spectrometer. A beta detector and a Germanium detector allowing the measurement of X-rays will complement the STARS. The beta detector could be a silicon detector combined with a plastic detector in order to measure beta-delayed protons and distinguish them from beta+ particles. The nuclear structure properties of low-lying states in some of the daughter nuclei are poorly known and the $LaBr_3$ modules of the new STARS array will allow providing nuclear structure information on these low-lying levels.

It is seen from the « chartbeam » website output that the intensities (pps) of the isotopes ^{97,98}Cd are reasonable to study their decay spectroscopy using a highly efficient decay station $(Na)^2$STAR. It is also important to note that the production intensity of the isotopes ^{98}Cd at the DESIR low-energy branch is about two orders of magnitude more than that of the ^{97}Cd, which nearly compensates for the similar order of magnitude difference in their βp branching. However, the production of ^{99}Cd is not listed in the above chart, though it should be highly possible to produce with enough intensity for the present study considering the intensities of the two neighboring isotopes, ^{98,100}Cd.

The production method of the nuclei of interest is as per the DESIR production chart available in the GANIL website and is given below for Cd isotopes.

Radioactive Beam	halflife	unit	Charge State	Intensity* (pps)			Primary Beam	Primary Beam Intensity (pμA/pps)	Primary Beam Power on ECS Target (kW)	Primary Beam Energy (MeV/nucleon)	RIB production target
				I_{ave}**	I_{min}***	I_{max}****					
97Cd	3,7	s	1+	2,80E+00	5,70E-01	1,40E+01	40Ca	6/4E+13	1,0	4,2	60Ni
97Cd	3,7	s	---	3,80E+01	7,60E+00	1,90E+02	40Ca	6/4E+13	1,0	4,2	60Ni
98Cd	9,2	s	1+	2,80E+02	7,10E+01	9,90E+02	46Ti	5/3E+13	0,9	3,8	58Ni
98Cd	9,2	s	---	3,60E+03	9,00E+02	1,30E+04	46Ti	5/3E+13	0,9	3,8	58Ni
100Cd	49,1	s	1+	2,00E+04	8,20E+03	5,40E+04	40Ca	6/4E+13	1,0	4,2	64Zn
100Cd	49,1	s	---	2,60E+05	1,00E+05	6,70E+05	40Ca	6/4E+13	1,0	4,2	64Zn
102Cd	5,5	m	1+	2,60E+04	7,60E+03	5,10E+04	58Ni	2/1E+13	0,5	4,5	50Cr
102Cd	5,5	m	---	3,20E+05	9,40E+04	6,30E+05	58Ni	2/1E+13	0,5	4,5	50Cr
103Cd	7,3	m	1+	3,70E+05	1,70E+05	8,40E+05	12C	30/2E+14	2,0	5,4	94Mo
103Cd	7,3	m	---	4,60E+06	2,20E+06	1,10E+07	12C	30/2E+14	2,0	5,4	94Mo

Color code :

36,4 Beam produced at S3 for ISOL-type experiments (Low energy branch, DESIR)

36,4 Rates at the focal plane of S3

In order to compute the required number of shifts, a minimal number of 10^5 beta-gamma coincidences with the STARS (with 70% efficiency for the TAS and a beta efficiency of 40%) has been considered. Some cases require larger intensities because of very large GS to GS branches. When the beta-p or the GS to GS branches are not known, we have assumed a conservative 20% of β-γ decays in the numbers below.

Run No.	Nucleus to study	Required no. of UTs	Comment
1	101In	7	Both TAS and HRS
2	98Cd	14	Both TAS and HRS
3	103In	5	
4	99Cd	12	Not in the chartbeam list. Assumed same pps as 98Cd
5	97Cd,99In	30	Production yields of these two need to be increased by about 4 times before these can be taken up

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