Study of exotic neutron-deficient nuclei close to ^{100}Sn using novel multinucleon transfer reactions

J.M. Keatings[1], J.F. Smith[2], H. Ayatollahzadeh, M. Bowry, R. Chapman, B.J.M. Hogg, B.S. Nara Singh, D. O'Donnell, M. Scheck
University of the West of Scotland, High Street, Paisley, PA1 2BE, UK

D. Mengoni, S. Lenzi
Università di Padova, I-35131 Padova, Italy

J.J. Valiente Dobon, G. De Angelis, D.R. Napoli
INFN, Laboratori Nazionali di Legnaro, I-35020 Legnaro, Italy

A.J. Boston, H.C. Boston, P.A. Butler, L.P. Gaffney, L. Harkness-Brennan, E. S. Paul
University of Liverpool, Oxford Street, Liverpool, L69 7ZE, UK

M.A. Bentley
University of York, Heslington, York, YO10 5DD, UK

M. Labiche, I.H. Lazarus, J. Simpson
STFC Daresbury Laboratory, Daresbury, Warrington, WA4 4AD, UK

P.T. Greenlees
University of Jyväskylä, FI-40014, Jyväskylä, Finland

Please not that we intend to submit an updated draft of this Letter of Intent within several days of the submission deadline.

Abstract
Multinucleon transfer reactions are known to provide a useful method of populating neutron-rich nuclei in gamma-ray spectroscopy experiments. Recent theoretical calculations have suggested that such reactions could also be used to produce neutron-deficient nuclei, but this has not been properly investigated in experiments. The calculations suggest that it may be possible to produce the neutron-deficient nuclei from $_{50}$Sn to $_{54}$Xe with reasonable cross sections. These nuclei are of considerable interest due to their proximity to N=Z ^{100}Sn. In the experiment we will also study the production yields of neutron-deficient nuclei above $^{100}_{50}$Sn with multinucleon transfer reactions. We will use a beam of $^{112}_{50}$Sn at 650 MeV on a thin $^{56}_{28}$Ni target. The beam-like reaction products will be identified using the PRISMA spectrometer, and the prompt decays of excited states will be measured using AGATA. To perform this measurement, we request 14 days of beam time.

[1]Spokesperson: James.Keatings@uws.ac.uk
[2] Spokesperson: John.F.Smith@uws.ac.uk

Motivation

Multinucleon transfer reactions have been demonstrated to be a very effective method of producing exotic nuclei on the neutron-rich side of the nuclear chart [1-4]. Such reactions have been used to identify new isotopes in the $Z \geq 92$ region [5,6,7] and to carry out gamma-ray spectroscopy on a range of neutron-rich nuclei. To date, they have not been used to produce nuclei in neutron-deficient regions. However, recent theoretical studies in Refs. [8,9,10] have suggested that the cross sections for the production of neutron-deficient nuclei are sufficient for use in experiments. For the neutron-deficient nuclei north-west of Sn, experiments have so far proceeded using fusion-evaporation reactions, with which typical cross-sections for the exotic nuclei of interest are in the region of a few μb down to nb. If larger cross sections can be achieved by the use of multinucleon transfer reactions then this would open up a range of potential new measurements and new physics.

The doubly-magic N=Z nucleus ^{100}Sn is of considerable interest in nuclear physics. The region close to ^{100}Sn is extremely hard to access experimentally [11,12] but there is significant motivation to study these nuclei. Nuclei in this region serve as some of the best testing grounds for proton-neutron interactions outside of a doubly-closed shell. The lightest Sn, Te, and Xe isotopes have also not been studied through γ-ray spectroscopy.

Outside of the light actinides around ^{224}Ra, and the neutron-rich lanthanides near to ^{146}Ba, the third region of octupole correlations is centred on the very neutron-deficient N=Z=56 nucleus ^{112}Ba. The nuclei near ^{112}Ba are unique in that both the proton and neutron Fermi levels lie close to the same octupole-driving $d_{5/2}$ and $h_{11/2}$ orbitals. Experimentally, the nuclei in this region are very hard to produce. As such there are currently only a few experimental hints of octupole corelations known in this region, for example in ^{112,114}Xe [1-4] and ^{118}Ba [5]. For ^{114}Xe the $B(E3)$ has been measured to be 70 W.u., which is one of the largest octupole strengths known [3]. Strutinsky calculations have predicted a peak along the Xe isotopic chain at $A = 110$ with $\beta_3 = 0.105$ [6], and Hartree-Fock-BCS methods have also predicted the $B(E3)$ to be approximately 20 W.u. [7]. However, more recent studies calculated potential energy surfaces with the SCMF approach and have predicted that no Xe isotopes have a ground state with $\beta_3 > 0$ [8]. These works highlight that current experimental information is insufficient to fully understand octupole correlations in this region. In this Letter of Intent we will discuss a possible proposal to further investigate octupole correlations in this region using multinucleon transfer reactions, which is a new experimental technique for this region, and in doing so aim to make a comprehensive study of the structure of $^{110-112}$Xe.

This unique region of the nuclear chart provides a chance to study single particle and collective behaviour. We would therefore like to further investigate the production of neutron-deficient nuclei using this method. We appreciate the feedback from a previous letter which was submitted, we have incorporated this feedback into this letter.

Experimental details

Here, we present a possible experiment in which we will us a multinucleon transfer reaction to (a) populate the nuclei ^{110,112}Xe in order to carry out gamma-ray spectroscopy of these nuclei with AGATA and (b) to measure the production cross sections of nuclei across the neutron-deficient Sn-Xe-Ba-Ce region to better understand the viability of multinucleon transfer as a production method of neutron-deficient nuclei. The yields of individual transfer reaction channels will be compared with theoretical calculations. A $^{112}_{50}$Sn beam with an energy of 650 MeV on a $^{58}_{28}$Ni target will be used. This gives a centre of mass energy equal to $1.4V_B$, where $V_B =$ 158.4 MeV. The grazing angle for this reaction has been calculated to be 24°. The specific cases of interest are ^{110,112}Xe which will be produced through the (+4p,-4n) and (+4p,-6n) transfer channels, respectively. The cross sections for these reactions have been calculated by Wu *et al.* [8] using the TDHF+GEMINI method to be 30 μb and 3 μb, respectively. The prompt γ rays will be measured at the target position using AGATA and the scattered beam-like partner being detected in PRISMA. The measurements of lifetimes of excited states could be measured by appropriate methods, such as $LaBr_3$(Ce) detectors.

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