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研究課題名（和文） Pushing the frontiers to superallowed decays near 100Sn at JAEA

研究課題名（英文） Pushing the frontiers to superallowed decays near 100Sn at JAEA

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研究成果の概要（和文）：陽子と中性子の数が同じで最も重い原子核を探索するため原子力機構タンデム加速器施設で、実験を行っている。
原子核の中でアルファ粒子がどのように形成されるかを理解するために必要となるこれらの原子核の崩壊特性を得るために、国際共同研究のもと新たな実験装置を開発し、試験的な実験を行った。その結果、1イベントではあるが、新同位体113Ba(Z=56、N=57)をはじめて合成することに成功した。本実験である108Xeおよび104Te原子核の合成を2015年12月から開始した。長期間の測定が必要であるため、今後も継続していく予定である。

研究成果の概要（英文）：An experimental program to discover and identify the heaviest possible nuclei with the same number of protons and neutrons was started at the JAEA Tandem accelerator laboratory. The decay properties of these isotopes provide important data to understand at a fundamental level how the alpha particle forms in the nucleus. A new setup was developed in collaboration with international colleagues. The discovery of new isotope113Ba (Z=56, N=57) was attempted. One observed event reveals that 113Ba was produced for the first time. The experiment for the discovery of 108Xe and 104Te, the ultimate goal of this program, started in December 2015. Due to the long measuring time needed, it will be resumed in a following experimental campaign.

研究分野： nuclear physics

キーワード： nuclear structure　alpha decay　proton-rich nuclei

１．研究開始当初の背景

(1) The study of “exotic” nuclei, i.e. nuclei with a large unbalance of protons (Z) and neutrons (N) compared to stable elements, is one of the main aims of nuclear research. From the structural and decay properties of such nuclei, in fact, it is often possible to understand more in depth the fundamental nuclear interactions and laws which govern all nuclei.

(2) One such example is the study of α-decay properties of nuclei in the region near ^{100}Sn. The widespread interest in the study of this region is because ^{100}Sn is the heaviest possible doubly-magic nucleus with equal number of neutrons and protons (N=Z=50). The unique feature of N=Z nuclei is that protons and neutrons occupy the same shell-model orbitals, leading to enhanced correlations between nucleons. Such correlations are predicted to increase the probability of α preformation in the nucleus, leading to the fastest, so-called “superallowed” α decay of ^{104}Te→^{100}Sn+α. The observation of this predicted decay would permit to understand at a more fundamental level the α-decay process.

２．研究の目的

(1) The aim of this project is the development of a new setup which would permit to measure for the first time proton-rich nuclei such as ^{113}Ba, ^{112}Ba, ^{108}Xe and ^{104}Te, and in particular to measure the predicted ^{104}Te super-allowed α decay at the JAEA Tandem laboratory. The degree of preformation can be deduced from the ^{104}Te α-decay half-life and energy.

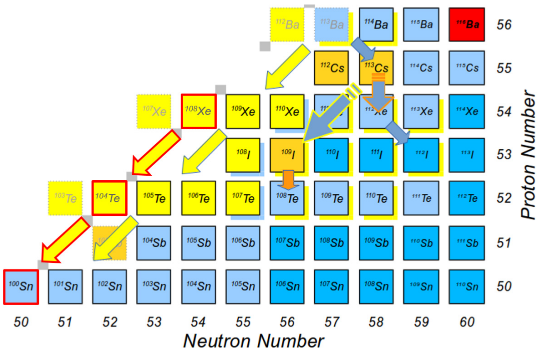

Fig.1 Nuclei near ^{100}Sn. Colors correspond to different decay modes (α: yellow, proton: orange, β: blue). The ^{108}Xe→^{104}Te→^{100}Sn decays are highlighted in red. The decay channels of ^{113}Ba are also shown by arrows.

(2) The unique signature of the successful production of ^{104}Te would consist in the detection of the two consecutive alpha decays ^{108}Xe→^{104}Te→^{100}Sn. Due to the short predicted half-life of ^{104}Te (<100 ns), the observation of this double-α chain can only be achieved by digitizing the signal and record the unique fingerprint corresponding to the “pileup” trace.

(3) The setup was developed at the JAEA Tandem in collaboration with colleagues from UT Knoxville, ORNL and the University of York. Because of the very low production cross section expected for ^{108}Xe (~100pb), an experimental technique of extreme selectivity had to be achieved. Preparatory tests were first carried out to confirm the sensitivity of the new setup. After studying the double-α chain ^{109}Xe→^{105}Te→^{101}Sn and the triple α chain ^{113}Ba→^{109}Xe→^{105}Te→^{101}Sn, the study of the ^{108}Xe chain was attempted.

３．研究の方法

(1) The production method for the desired isotopes consists of fusion evaporation reactions using intense (~30pnA) ^{58}Ni beams onto a rotating ^{54}Fe and ^{58}Ni targets, approximately 0.5 mg/cm^2 thick.

(2) The main difficulty to be overcome is the combination of very small production cross-sections for ^{109}Xe, ^{113}Ba, and ^{108}Xe, combined with orders of magnitude larger production of contaminant nuclei. For this reason, the Recoil Mass Separator ① (RMS) at the JAEA tandem was employed to separate in-flight the evaporation residues (ERs) produced in the reaction according to their mass over charge (m/q) ratio.

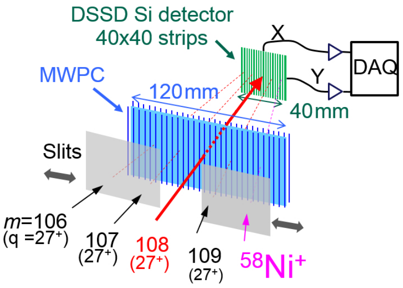

Fig. 2 Schematic diagram of the main detection setup in the focal plane chamber of the RMS. Only isotopes of the same m/q are implanted in the Si detector.

(3) The ERs, such as ^{113}Ba or ^{108}Xe, reach the RMS focal plane chamber where a new setup has been installed. The main components are a Multi-Wire Proportional Chamber (MWPC) and a 40x40 strip 65-μm-thick DSSD Silicon detector (Fig 2). The ERs are implanted in the DSSD, where they eventually decay. Coincidence with the MWPC permits to distinguish between implant events and decay events in the DSSD. The signal were recorded and digitized using the UTK/ ORNL digital data acquisition system ②. Mechanical

slits were developed and included in the chamber to prevent the implantation of isotopes of other masses on the Silicon DSSD detector, thus reducing the background as much as possible.

(4) Additional detectors were also installed to enhance the sensitivity of the setup: the chamber was surrounded by an array of NaI detectors, to be used as a VETO to reduce the background from β-delayed proton events. 1mm-thick Si pin detector were installed behind and at 45 degrees from the DSSD, to increase the efficiency for events in which the α particles do not lose their full energy in the DSSD.

４．研究成果

(1) In a first experiment, using the reaction ^{58}Ni+^{54}Fe→^{109}Xe+3n at 220 MeV beam energy, six ^{109}Xe→^{105}Te→^{101}Sn double-α chains were observed, yielding the first and only confirmation of these decays, previously observed at ORNL ③. Figure 3 shows one example of a typical pile-up pulse corresponding to the fast consecutive emission of the ^{109}Xe [$\tau_{1/2}$=13(2) ms] and ^{105}Te [$\tau_{1/2}$=620(70)ns] α particles.

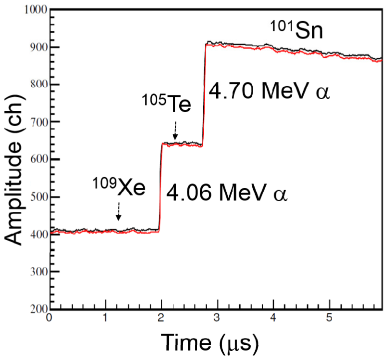

Fig. 3 Pile-up trace from the ^{109}Xe→^{105}Te→^{101}Sn decay chain detected in one pixel in the DSSD at JAEA.

(2) As a second step, the discovery of the new isotope ^{113}Ba [Z=56,N=57,$t_{1/2}$~sec] was attempted. The chosen reaction was ^{58}Ni+^{58}Ni →^{113}Ba+3n, at 245 MeV. ^{113}Ba mainly decays via β-decay to ^{113}Cs, but a nearly ~10% α-decay branch was predicted ④, leading to the triple decay chain ^{113}Ba→^{109}Xe→^{105}Te→^{101}Sn (see Fig.1). The half-life of ^{113}Ba is unknown but much longer (~sec) than ^{109}Xe and ^{105}Te, so the strategy was to detect the known pile-up of ^{109}Xe and look back in time in the data to find the ^{113}Ba α emitted in the same DSSD pixel. In a 10-day experiment, only one pileup event, belonging to the decay of ^{109}Xe and most likely originating from the α decay of ^{113}Ba, was observed (Fig. 3). Due to the shallow implantation of the ^{113}Ba recoils in the DSSD, the α particle from the original ^{113}Ba decay escaped without being detected. The measured rate of ^{113}Ba α decays is much smaller than expected, based on the calculations using the HIVAP ④ code. A possible explanation is a much smaller than predicted relative α-decay branching ratio, smaller than 1 % instead of 10 % ⑤. This low branching ratio value is closer to the recent JAEA evaluation ⑥. This measurement gives the first indication about the decay properties of ^{113}Ba, which has not been measured at any other facility. This experiment also revealed that the best way to produce ^{104}Te is by studying the double-α chain ^{108}Xe→^{104}Te→^{100}Sn instead of the triple-α chain starting with ^{112}Ba.

(3) The ^{108}Xe→^{104}Te→^{100}Sn experiment was attempted in December 2015. The chosen reaction was ^{58}Ni+^{54}Fe→^{108}Xe+4n, at 245 MeV beam energy. For this measurement, a new detector, faster and complementary to the DSSD, was developed. The new detector uses a thin YAP scintillator with a segmented light guide for a pixelated output. The new detector was tested with beam and has a rise time of 10 ns and a 9% energy resolution for a 3.5 MeV α decay. 2mm pixel size was reconstructed from the four position signals, which were readout using a resistive network. This detector was employed to increase the chance of observing the ^{108}Xe double-α chain, especially if it were to be of only few tens of nanoseconds. Unfortunately, because of problems with the Tandem accelerator, less than 10% of the required data was collected and no indication of the ^{108}Xe→^{104}Te→^{100}Sn chain was yet observed. Due to the long needed measuring time, the experiment will be resumed in a following experiment campaign. The new setup is however now ready to carry out this ambitious measurement, and to push the frontier to ^{108}Xe and ^{104}Te.

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５．主な発表論文等

（研究代表者、研究分担者及び連携研究者には下線）

〔雑誌論文〕（計 0 件）

〔学会発表〕（計 1 件）

①R. Orlandi *et al.,* "Exotic Proton-rich Nuclei at the JAEA-TANDEM Facility: a New Setup to Study Rare Decays at the Recoil Mass Separator", TAN15 Conference, Urabandai Royal Hotel (Yamagun, Fukushima) May 25-29, 2015. (poster presentation)

〔図書〕（計 0 件）

〔産業財産権〕
○出願状況（計 0 件）
○取得状況（計 0 件）

６．研究組織

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