Yield of neutron-rich ^{183,184}Hf isotopes from KISS

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In the exploration of multi-quasiparticle high-K isomers within the neutron-rich $A \sim$180–190 region, theoretical predictions suggest their significant energetic favorability and prolonged half-lives.[1)] Furthermore, a prolate-to-oblate shape/phase transition with increasing neutron number is expected to result in prolate high-K isomers decaying to oblate low-K states.[2)] Despite these theoretical insights, experimental investigations face challenges due to the neutron richness and refractory chemical properties of elements in the hafnium (Z = 72) to platinum (Z = 78) range, constraining possibilities for comprehensive studies.

Remarkable progress was made with the discovery of long-lived ($T_{1/2}$ > 1 s) isomers in ^{183,184}Hf and ^{186,187}Ta (among others) using projectile-fragmentation reactions at the GSI experimental storage ring (ESR).[3)] Moreover, details of the structure of the tantalum isomers have recently been obtained with multi-nucleon transfer (MNT) reactions and electron-γ spectroscopy at KISS.[4,5)] The present report focuses on research with the KISS facility to study the spectroscopy of the neutron-rich hafnium isotopes, specifically ^{183}Hf and ^{184}Hf. The experiment spanned six days and used a ^{136}Xe beam incident on a natural tungsten target. Recoiling reaction products were stopped in a high-pressure argon gas cell.

Following laser ionization and mass separation, decays were recorded using a multi-segmented proportional gas counter[6,7)] for β and conversion electrons, and four Super-Clover germanium detectors for γ rays. The mass-separated ions came to rest on a tape in the center of the electron-γ detection system. After a preset time of data taking, T_{on}, the beam was turned off and a second set of data was accumulated for a time, T_{off}, followed by a movement of the tape to remove the residual activity. The cycle was repeated a number of times, yielding decay radiation energies and intensities as a function of time. For ^{183}Hf, two different time sequences were used for the examination of its isomeric and β decays: $T_{on/off}$ = 5-min/10-s and 1-h/1-h.

Fig. 1 shows a β-γ coincidence spectrum for ^{183}Hf, with the 1-h/1-h time sequence. Known transitions in the β decay of ^{183}Hf ($T_{1/2}$ = 1.02 h) are labeled. The two most intense peaks at energies 73.2 and 783.2 keV have been used to obtain the production yield of 0.81(7) ion/s of ^{183}Hf, assuming an efficiency of 40% for the β detector. In a similar way, the yield of ^{184}Hf ($T_{1/2}$ = 4.12 h) was found to be 0.18(4) ion/s, using β-delayed γ-ray intensities. The primary ^{136}Xe beam current was $\sim$50 particle nA. Although small, the yields of ^{183}Hf and ^{184}Hf represent the first production of neutron-rich Hf^{+} ions with an isotope separator using gas stopping and laser ionization. It is also notable that, as the more volatile fluoride, neutron-rich HfF_3^{+} ions have been produced at ISOLDE.[8)]

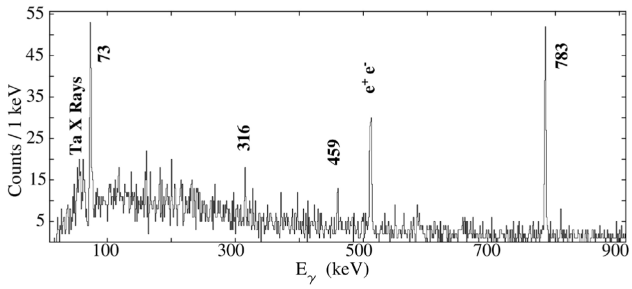

Fig. 1. Gamma-ray spectrum of ^{183}Hf decays in coincidence with β particles, with a tape cycle of $T_{on/off}$ = 1-h/1-h.

It can be seen in the Fig. 1 spectrum that there appear to be many additional (unlabeled) low-intensity γ-ray peaks in the energy range 100–450 keV. Data analysis is in progress to determine if any of these might be associated with the decay of a high-K isomer. Such an isomer was previously identified from a single isomeric ion of ^{183}Hf^{71+} in the ESR, at 1464(64) keV relative to the ^{183}Hf ground state.[3)]

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