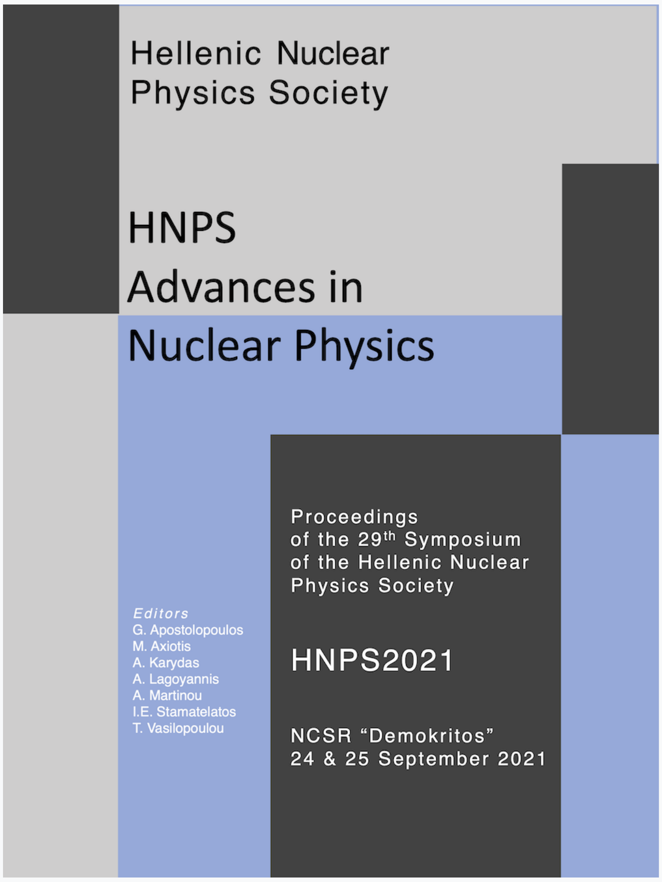
HNPS Advances in Nuclear Physics

Vol 28 (2021)

HNPS2021



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doi: [10.12681/hnps.3612](https://doi.org/10.12681/hnps.3612)

Experimental Study of the Nuclear Structure of ^{180}Hf: Preliminary results*

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Abstract This work features preliminary results from a recent experimental campaign at IFIN-HH, Romania, aimed at measuring lifetimes of excited states in the neutron-rich ^{180}Hf, by means of the RDDS technique. The ^{181}Ta(^{11}B,^{12}C)^{180}Hf proton pick-up reaction was used to populate excited states in the ^{180}Hf nucleus. The ROSPHERE array loaded with 25 HPGe detectors was employed for the detection of the γ transitions depopulating the levels of interest. The array was coupled to the SORCERER particle detector and a plunger device enabling the study of p-γ and p-γ-γ coinciding events. Six different plunger foil distances were chosen, allowing for the construction of the decay curves of the observed γ transitions of interest, from which the corresponding level lifetimes can subsequently be deduced.

Keywords ^{180}Hf, lifetimes, RDDS, plunger

INTRODUCTION

The Hf isotopic chain belongs to the rare-earth region of the nuclear chart, a region presenting many attractive cases for phenomena related to nuclear structure. The neutron-rich, even-even nucleus ^{180}Hf (Z=72) is a particularly attractive case to be studied experimentally, due to its multi-faceted structure, consisting of a rotational ground state band (gsb), but also several other collective bands, K-isomers, and non-band members [1,2].

Numerous theoretical works have been focused around the Hf isotopic chain over the last few years (see for example Refs. [3–9]), using a variety of models. Among them is the recently developed proxy-SU(3) [10,11], which predicts shape coexistence [12] for the even-even hafnium isotopes, with ^{180}Hf being well inside the shape coexistence window [11]. Yet the experimental data regarding lifetimes, B(E2) reduced transition rates, and electromagnetic moments remain scarce [2,13]. It was only recently that the lifetimes of the first few levels (up to the 6^+ state) of the g.s. band were measured for ^{180}Hf, by means of fast-electronic scintillation timing [14], while the exploratory experiment performed by our group at IFIN-HH, in Romania, in April 2019, was focused at the determination of spins, parities and mixing ratios for exited states in ^{180}Hf [15].

This work features preliminary results from our most recent experimental campaign at the IFIN-HH laboratory, in Romania, aimed at measuring lifetimes of excited states in ^{180}Hf via the Recoil Distance Doppler Shift technique (RDDS).

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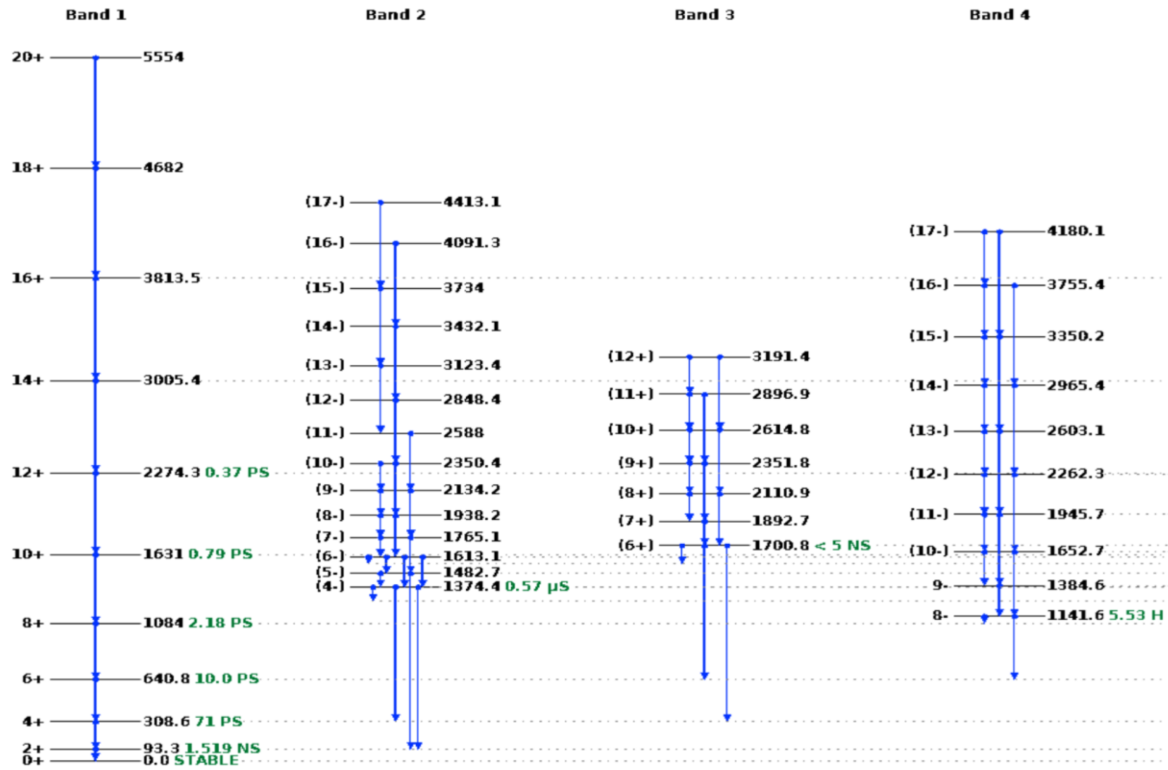

Figure 1. *Partial level scheme of ^{180}Hf, adapted from Ref. [2].*

EXPERIMENTAL DETAILS

An ^{11}B beam was accelerated at a laboratory energy of 47 MeV by the 9 MV TANDEM accelerator of the IFIN-HH laboratory, in Magurele, Romania. The beam was incident on a 1 mg/cm^2 self-supported metallic ^{nat}Ta target (99.99% natural abundance in ^{181}Ta [2]), in order to populate excited states in ^{180}Hf via the proton-pickup reaction ^{181}Ta(^{11}B,^{12}C)^{180}Hf.

The ROSPHERE [16] array with 25 HPGe detectors mounted was employed for the detection of the γ decays of product nuclei. Coupled to it was the SORCERER [17] solar cell particle detector array, which allowed for the implementation of p-γ and p-γ-γ coincidence techniques to isolate the decays of interest. The detector array used in our experiment is presented in Fig. 2.

The Recoil Distance Doppler Shift (RDDS) [18] technique was implemented for the measurement of lifetimes of excited states in ^{180}Hf. It is a well established method for picosecond lifetime measurements of excited nuclear states [18]. At t=0, a beam-induced nuclear reaction on a thin target produces the excited nuclear states of interest. Due to momentum transfer, excited nuclei leave the target with a velocity u, and are stopped inside the stopper foil after a well-defined flight-time $t_f = d/u$, where d is the target-stopper distance. Depending on the distance, some nuclei cannot reach the stopper foil before decaying, and thus they decay in flight, emitting γ rays which are Doppler shifted. Through comparison of the changes in the areas of the shifted and unshifted peaks, for varying target-stopper distances, the lifetime of interest can be determined. Six different distances where chosen for the experiment, ranging 15–260 μm.

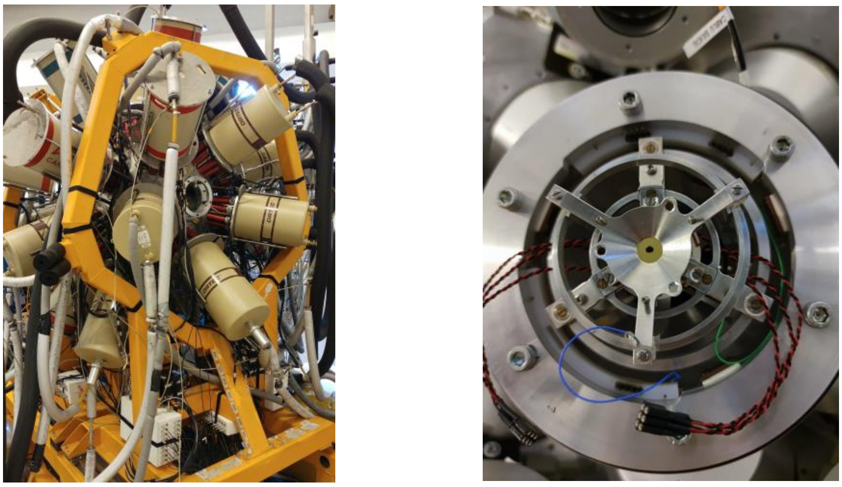

Figure 2. *(Left) The ROSPHERE array in the configuration used in our experiment; (Right) The plunger device mounted inside the ROPSHERE target chamber.*

RESULTS AND DISCUSSION

The p-γ and p-γ-γ coincidence techniques enabled through the application of the SORCERER solar cell particle detector, allowed for a distinction between the various light ejectiles (^{12}C, ^{11}B, etc.) detected, thus allowing for the identification of the reaction products (^{180}Hf, ^{181}Ta, etc.). A typical particle spectrum, recorded by SORCERER is shown in Fig. 3.

For each distance, a coincidence condition (gate) was placed on the ^{12}C peak in the particle spectra, corresponding to the ^{180}Hf gamma spectra. Next, two-fold (i.e. γ-γ) events were sorted into three-dimensional cubes for further analysis, based on the relative angle of each ROSPHERE detector ring. The obtained spectra for each distance are presented in Fig. 4, where the shifted and unshifted components of the $6^+ \rightarrow 4^+$ g.s. band transition are shown to be clearly separated. This transition has a known lifetime of $t_{1/2}$=10.0(7) ps [2], and can serve as a validation of our experimental method.

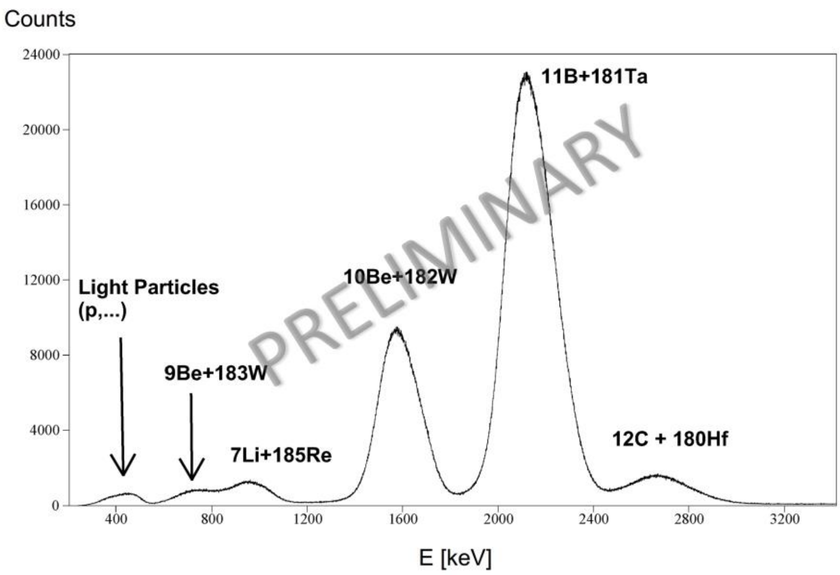

Figure 3. *Typical particle spectrum recorded by the SORCERER detector array. Marked above each peak is the ejectile produced by the corresponding reaction channel.*

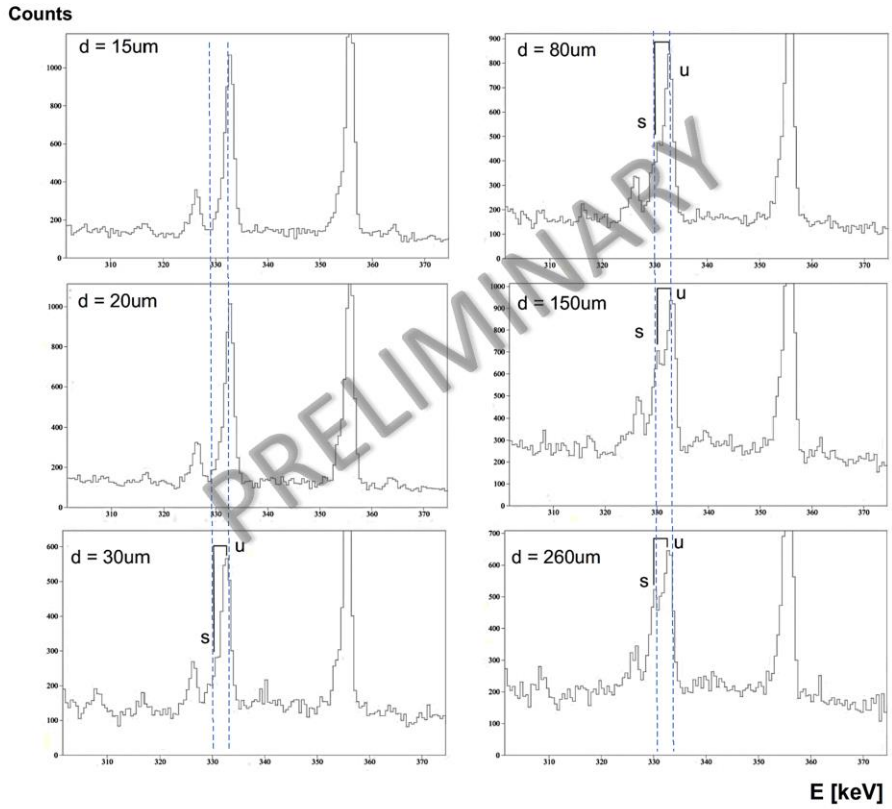

Figure 4. *The 6⁺ → 4⁺ g.s. transition in ^{180}Hf ($t_{1/2}$ = 10.0(7) ps), for six target-stopper distances (15–260 μm). Notice the separation between shifted (s) and unshifted (u) components.*

CONCLUSIONS

This work features preliminary results from the recent experimental campaign at IFIN-HH, in Romania, focused on lifetime measurements of excited states in ^{180}Hf, via the RDDS technique.

Over the course of the analysis, the rest of the observed transitions in ^{180}Hf, as well as in the rest of the produced nuclei (e.g. ^{182}W, Pt isotopes) will be examined for shifts, in an attempt to construct their respective decay curves and subsequently deduce their lifetimes.

In addition to the experimental results, theoretical predictions using a variety of models (e.g. proxy-SU(3), IBM, etc.) will be compared with the experimental results and are expected to provide new information on the dynamical shape evolution of the isotopes considered, including shape coexistence, as expected to be present in this region of the nuclear chart [12].

Acknowledgements

This research work was supported by the Hellenic Foundation for Research and Innovation (HFRI) under the HFRI PhD Fellowship grant (Fellowship Number: 101742/2019) for AZ.

H.F.R.I. Hellenic Foundation for Research & Innovation

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