Measurement of the Excitation Function for the $^{nat}Lu(p,X)^{175}Hf$ Reactions

Kyle D. Chapkin, Cyclotron Institute, Texas A&M University
(REU student from Rice University)
M.C. Alfonso, M.E. Bennett, D.A. Mayorov, T.A. Werke, C.M. Folden III

Introduction

The chemistry of heavy elements continues to be a topic of interest in current research. In preparation for studies aimed at investigating the chemical properties of Rf, synthesis of longer-lived radioactive Hf, a homolog, is necessary to develop suitable chemical separation techniques and to establish the expected trends and behavior in Rf [1]. This experiment is designed to measure the excitation function of the $^{nat}Lu(p,X)^{175}Hf$ reactions and show that ^{175}Hf can be produced for off-line chemical studies at the Cyclotron Institute.

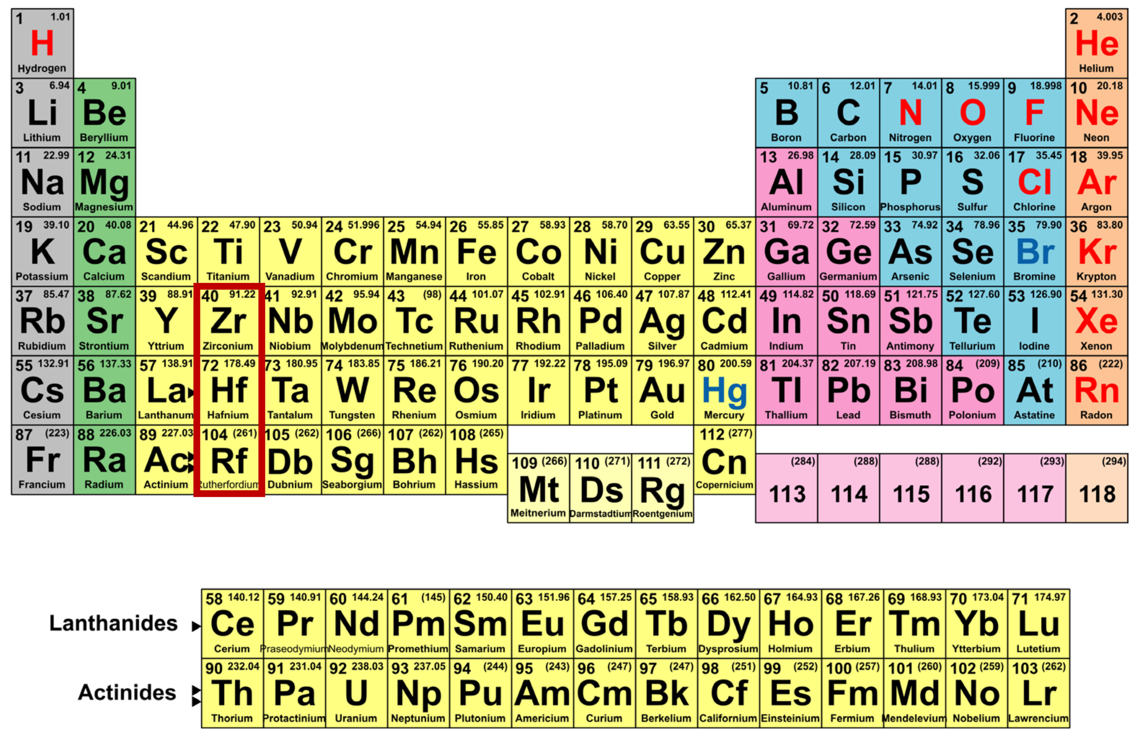

Figure 1. The Periodic Table of Elements as of 2011. Green box contains element of interest Rf, and its homologs.

Experimental Approach

Foils were pressed into a chamber by a metal rod, and then held into place. Two plastic insulators are put on each end of the target chamber. At the front, a collimator is connected to a -300 V bias to act as an electron suppressor. While the back of the chamber acts as a Faraday cup and is connected to a current integrator, so the beam dose could be measured.

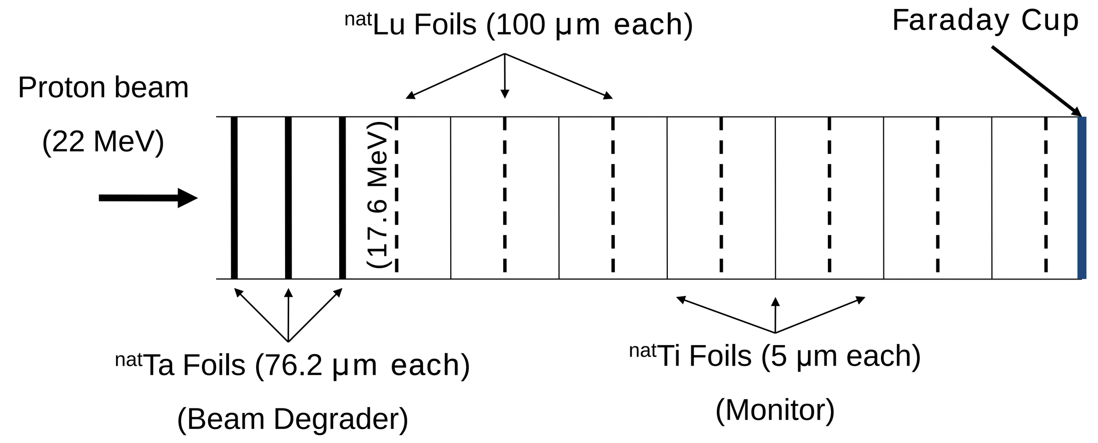

Figure 2. Orientation of foils inside chamber. Left side shows the front where the proton beam hits the targets.

Energetically Allowable Reactions	
$^{176}Lu(p,n)^{176}Hf$	$^{49}Ti(p,2n)^{48}V$
$^{49}Ti(p,n)^{49}V$	$^{176}Lu(p,3n)^{174}Hf$
$^{175}Lu(p,n)^{175}Hf$	$^{176}Lu(p,p)^{176}Lu$
$^{50}Ti(p,n)^{50}V$	$^{175}Lu(p,p)^{175}Lu$
$^{47}Ti(p,n)^{47}V$	$^{49}Ti(p,pn)^{48}Ti$
$^{48}Ti(p,n)^{48}V$	$^{49}Ti(p,^{4}He)^{46}Sc$
$^{50}Ti(p,p)^{50}Ti$	$^{48}Ti(p,2n)^{47}V$
$^{49}Ti(p,p)^{49}Ti$	$^{50}Ti(p,^{4}He)^{47}Sc$
$^{48}Ti(p,p)^{48}Ti$	$^{47}Ti(p,pn)^{46}Ti$
$^{47}Ti(p,p)^{47}Ti$	$^{47}Ti(p,^{4}He)^{44}Sc$
$^{46}Ti(p,p)^{46}Ti$	$^{48}Ti(p,^{4}He)^{45}Sc$
$^{176}Lu(p,2n)^{175}Hf$	$^{175}Lu(p,3n)^{173}Hf$
$^{46}Ti(p,n)^{46}V$	$^{47}Ti(p,2n)^{46}V$
$^{175}Lu(p,2n)^{174}Hf$	$^{46}Ti(p,^{4}He)^{43}Sc$
$^{50}Ti(p,2n)^{49}V$	$^{50}Ti(p,pn)^{49}Ti$
	$^{48}Ti(p,pn)^{47}Ti$

Table 1. List of expected products for Ti and Lu foils for given initial proton-beam energy of 17.6 MeV; found by calculating the thresholds of the reactions and compared to the energy available to the system

Table 1 shows reactions that can potentially occur at the available proton energy. $^{nat}Ti(p,X)^{48}V$ reactions were used as a beam monitor because the product has a relatively large production rate that peaks over the same range of energies as the excitation function of ^{175}Hf, making it the ideal monitor.

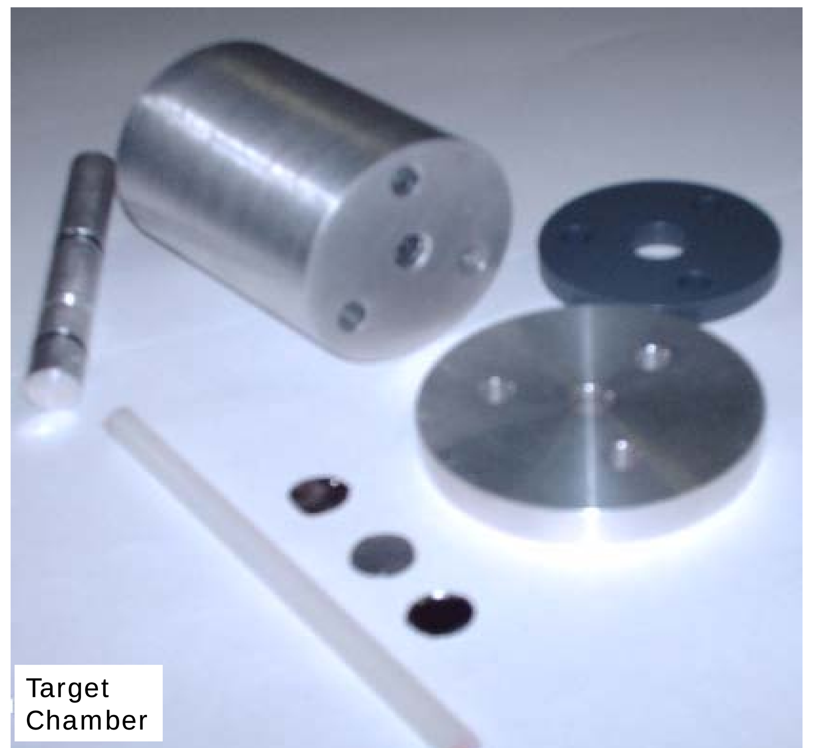

Figure 3. Picture of target chamber, unassembled.

A 22 MeV proton beam bombarded the stack of foils, as shown in Figure 2, for 158.6 minutes at an average beam intensity of $1.2x10^{10}$ particles/sec. The ^{nat}Ta foils, at the head of the stack, act as beam degraders, and decreased the energy of the proton-beam to 17.6 MeV by the time the protons reach the first ^{nat}Lu foil. The interspersed ^{nat}Ti foils act as monitors; the excitation function for the $^{nat}Ti(p,X)^{48}V$ reaction is accurately measured, and is used to determined the beam energy and intensity throughout the irradiated foils. The $^{nat}Lu(p,X)^{175}Hf$ reaction is under investigation for the experiment to determine the optimal beam energies for the future production of ^{175}Hf.

Upon completion of irradiation time, the samples were allowed to cool then extracted. The total time until the first measurement was 92.67 minutes. A HPGe detector was calibrated by a known ^{152}Eu source using 10 gamma lines to attain the efficiency of the detector: 0.21% for ^{nat}Ti and 0.44% for ^{nat}Lu. Count time for each foil differed depending on activity level, ranging from 57.83 minutes 6.98 hours. The length of each counting time was determined to achieve a net count of 10,000 to reduce statistical uncertainty.

Product	Eγ (keV)	I(%)	$t_{1/2}$ (day)
^{175}Hf	343.4	80±3	70±2
^{48}V	983.525	99.98±0.002	15.9735±.0025
^{48}V	1312.106	97.5±0.8	15.9735±0.0025

Table 2. Gamma energies, intensities, and half-lives of products of interest [3].

Table 2 contains the gamma energies of the products of interest that have a high enough intensity to be clearly seen in the spectra. ^{48}V has two intense peaks at 983.525 and 1312.106 keV, though only the 983.525 peak was used in later calculations of the cross section. ^{175}Hf has only one gamma energy of interest at 343.4 keV. Both product's half-lives are sufficiently long that decay corrections are negligible.

Results

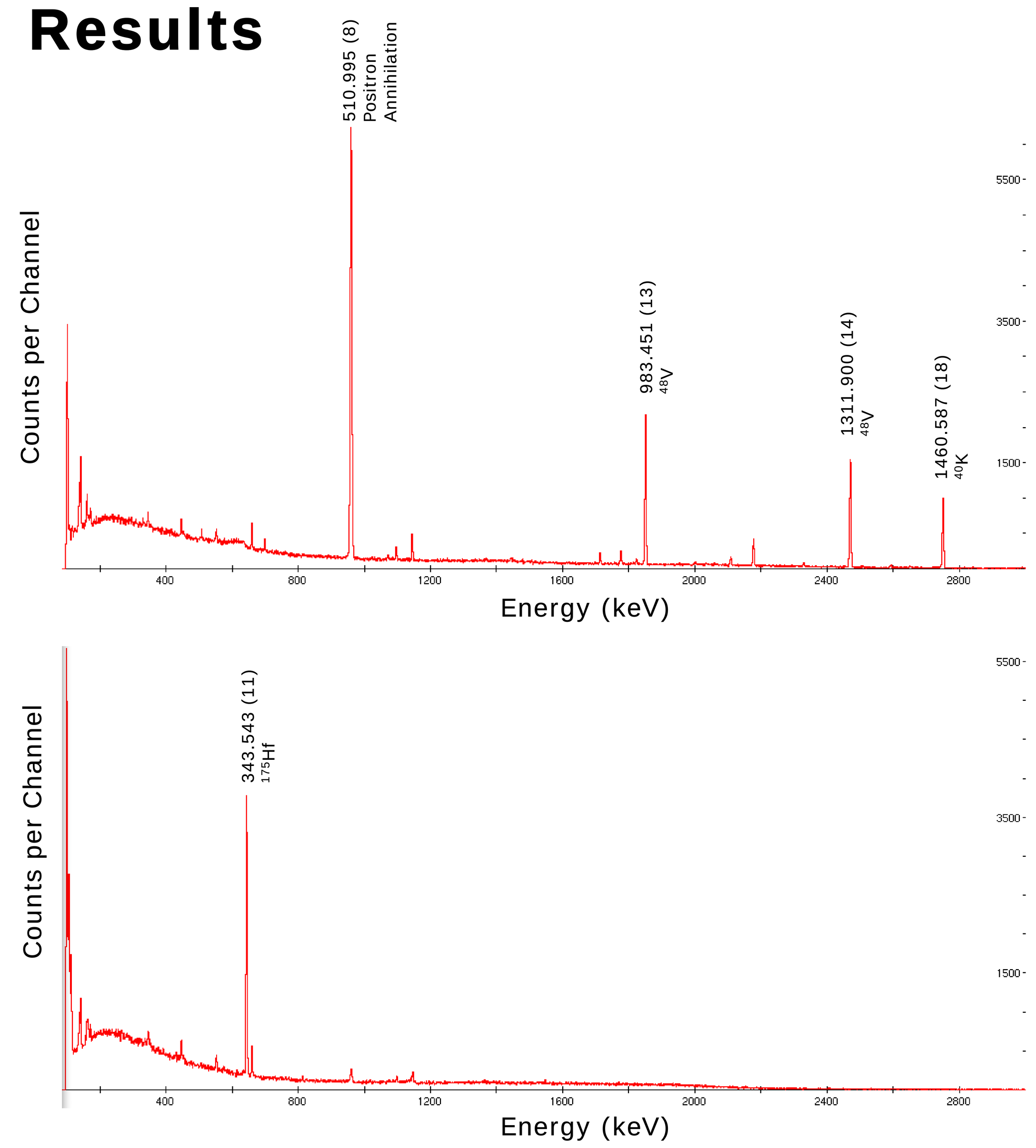

Figure 4. Spectra of an typical Ti and Lu foils from HPGe detector. Significant peaks are taken from [3].

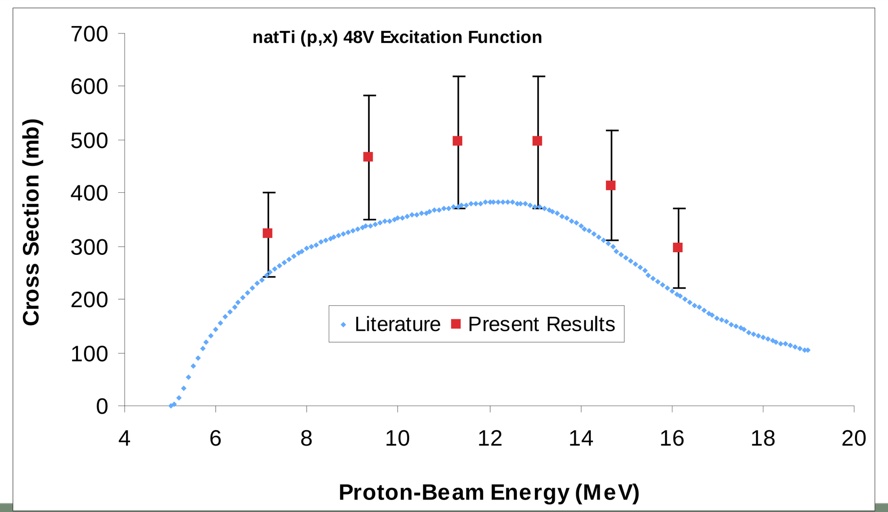

Figure 5. Excitation function for $^{nat}Ti(p,X)^{48}V$ reactions. Data points in red show experimental results of the excitation function in comparison to literature [2].

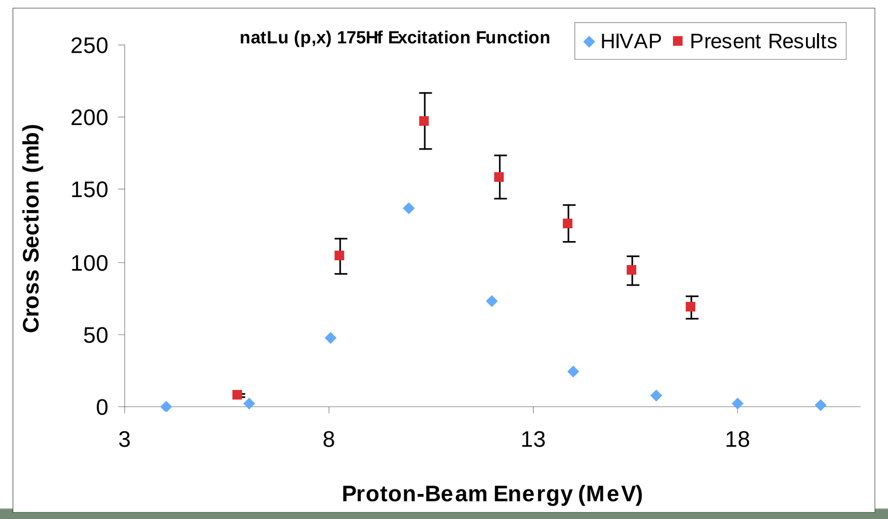

Figure 6. Excitation function for $^{nat}Lu(p,X)^{175}Hf$ reaction. Data points in red show experimental results of the excitation function in comparison to the HIVAP code [4].

The ^{nat}Ti reaction shows a peak cross section of 500±120 mb at a proton energy of 13.1 MeV. The latter results are in agreement with literature [2]. These data confirm that the energy loss calculations are correct. The ^{175}Hf excitation function shows a peak cross section of 197±19 mb at a proton energy of 10.3 MeV. The data are in agreement with theoretical predictions made by the HIVAP code [3].

Conclusions

These results show that ^{175}Hf can be produced for off-line chemical studies at the Cyclotron Institute.

References

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[2] F. Tarkanyi *et al.*, *Beam Monitor Reactions*, IAEA-TECDOC-1211, (IAEA, Vienna, 2001) p. 49; www-nds.iaea.or.at/medical.
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