Activation cross sections of alpha particle-induced reactions on natural hafnium up to 50 MeV†

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The ^{178m}Ta ($T_{1/2} = 9.31$ min) radioisotope is suitable for therapeutic applications owing to the high ionization capability of $K_{\alpha1}$ and $K_{\alpha2}$ radiation it emits (60%). The distribution of the injected isotope in the human body can be tracked using a positron emission tomography (PET) camera by utilizing its partial positron decay mode (total β^+ decay: 1.24%). An alternative production route for the medically interesting ^{178m}Ta radioisotope is the ^{178}W/^{178m}Ta generator system. To explore this possibility, activation cross sections of the ^{nat}Hf$(\alpha, x)^{178}$W ($T_{1/2} = 21.6$ d) reaction were investigated up to 50 MeV.

The experiment was performed at the RIKEN AVF cyclotron. The stacked-foil activation technique and high-resolution γ-ray spectrometry were applied. The stacked-foil target was assembled using pure metallic foils of ^{nat}Hf and ^{nat}Ti from Nilaco Corp., Japan with average thicknesses of 10.34 and 5.34 μm, respectively. Both the Hf and the Ti foils were inserted into the stack in pairs to compensate for the activity loss due to the recoil effect. The target was irradiated with a 51.0-MeV α-particle beam for 1 h. The incident beam energy was measured using the time-of-flight method.[1)] The energy loss of the bombarding alpha particles was calculated using the semi-empirical formula of Andersen and Ziegler.[2)] The average beam intensity measured using a Faraday cup was cross checked with the ^{nat}Ti$(\alpha, x)^{51}$Cr monitor reaction. The experimentally determined cross sections for the ^{nat}Ti$(\alpha, x)^{51}$Cr monitor reaction agreed perfectly with their recommended value[3)]; therefore, the primary beam parameters were accepted in further data analysis. The γ-ray spectra of each irradiated foil were recorded using a high-resolution high-purity germanium (HPGE) detector without chemical separation. Five series of gamma-ray measurements were performed with increasing cooling times to observe the decay of the reaction products. Reaction and decay data for the data analysis were taken from the NuDat 2.7 database.[4)]

The production of tungsten isotopes from ^{173}W to ^{184}W was possible with the used alpha-particle parameters on a natural hafnium target. Due to limitation of the used experimental technique and the decay parameters of those isotopes cross sections were derived only for the ^{176,177,178}W radionuclides in our experiments. As the radionuclide 178 W can be produced on all the six stable isotopes of hafnium with the applied 51 MeV alpha-particle beam, the resulting excitation function has a complex shape. The practical threshold energy of this process is approximately 20 MeV because the very low yield of the ^{174}Hf$(\alpha, \gamma)^{178}$W reaction did not provide a measurable contribution. Since no gamma emission follows the decay of ^{178}W the $E_\gamma = 1340.85$ and $E_\gamma = 1350.55$ keV gamma lines of ^{178m}Ta and its decay product were used in the data analysis. The applied cooling time ensured the complete decay of the directly produced ^{178m}Ta and equilibrium between the decaying ^{178}W and ^{178m}Ta.

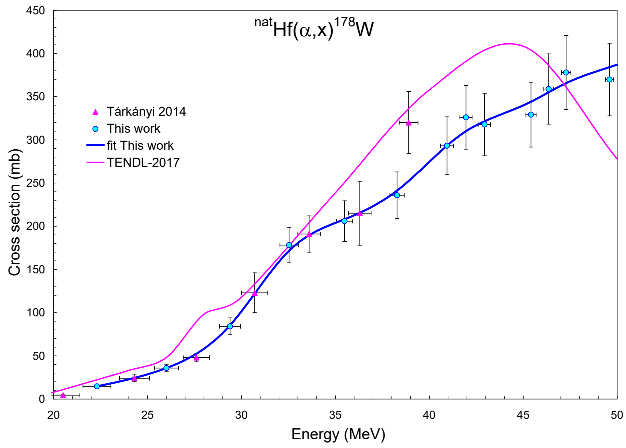

Fig. 1. Excitation function of the ^{nat}Hf$(\alpha, x)^{178}$W reaction in comparison with previous experimental data and the result of the model calculation taken from the TENDL-2017 database.[5)]

The experimental data are in good agreement with each other, while the TENDL-2017[5)] prediction follows the tendency of the experimental data up to 44 MeV.

In addition to the obtained cross sections of the ^{nat}Hf$(\alpha, x)^{178}$W reaction, cross sections for the ^{nat}Hf$(\alpha, x)^{176,177}$W, ^{nat}Hf$(\alpha, x)^{175,176,177,178g,180g,182g,183}$Ta, and ^{nat}Hf$(\alpha, x)^{173,175,179m2,180m,181}$Hf processes were determined. The results can contribute to develop the ^{178}W/^{178m}Ta generator system and to estimate the expected radio-impurity due to the co-production of other radionuclides.

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