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## Production cross sections of Nb and Ta isotopes in the (p,x) and (d,x) reactions on natZr and natHf

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To perform chemical experiments of superheavy elements (SHEs) on a single-atom scale, it is important to investigate the optimal experimental conditions in advance using long-lived and carrier-free radiotracers of their homologue elements. The isotopes  $^{95}\text{Nb}$  ( $T_{1/2} = 34.991$  d) and  $^{179}\text{Ta}$  ( $T_{1/2} = 1.82$  y) are the useful radiotracers for the basic studies of element 105, Db [1,2]. In this work, we measured the excitation functions for production of  $^{95}\text{Nb}$  and  $^{179}\text{Ta}$  as well as other isotopes in the proton- and deuteron-induced reactions on natZr and natHf for application studies. Experiments were performed with the AVF cyclotron at the RI Beam Factory in RIKEN, Japan. A well-established stacked-foil technique was used for measurements of the excitation functions. The stacks of natZr/natCu and natHf/natCu were irradiated by the 14-MeV proton beam, while those of natZr/natTi/natTa and natHf/natTi were irradiated by the 24-MeV deuteron beam. After the irradiation, gamma and X rays of each metallic foil were measured by Ge detectors to determine the activities of the produced nuclides. The cross sections of  $^{90}\text{g}, ^{91}\text{m}, ^{92}\text{m}, ^{95}\text{m}, ^{95}\text{g}, ^{96}\text{Nb}$ ,  $^{95}\text{Zr}$ ,  $^{87}\text{g}, ^{88}\text{Y}$ ,  $^{175}, ^{176}, ^{177}, ^{178}\text{a}, ^{179}\text{Ta}$ , and  $^{175}\text{Hf}$  were measured in the (p,x) reactions, whereas those of  $^{90}\text{g}, ^{91}\text{m}, ^{92}\text{m}, ^{95}\text{m}, ^{95}\text{g}, ^{96}\text{Nb}$ ,  $^{95}, ^{97}\text{Zr}$ ,  $^{87}\text{m}, ^{87}\text{g}, ^{88}\text{Y}$ ,  $^{175}, ^{176}, ^{178}\text{a}, ^{179}, ^{180}\text{g}, ^{175}, ^{179}\text{m}, ^{180}\text{m}, ^{181}\text{Hf}$  were measured in the (d,x) reactions. The excitation function of the natHf(d,x) $^{179}\text{Ta}$  reaction was measured for the first time. The obtained cross sections were compared with the data in the literatures and with the theoretical cross sections calculated by the TALYS code [3]. In the proton-induced reactions, the calculation reproduced well the measured production cross sections except for some nuclides which have isomeric states. On the other hand, only the partial agreements among the measured cross sections and predicted ones were found in the deuteron-induced reactions. Thick-target yields of the observed nuclides were deduced from the measured production cross sections.

### References

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- [3] A. J. Koning et al., TALYS-1.0. In: *Proceedings of the international conference on nuclear data for science and technology*, April 22-27, 2007. EDP Sciences, Nice, France, pp. 211-214.

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