Cross sections of alpha-particle-induced reactions on ^{nat}Ni: Production of ^{67}Cu[†]

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^{67}Cu is considered one of the most promising radioisotopes in targeted radio-immunotherapy. It is a β^--emitter with a mean β^- energy ($E_\beta^- = 141$ keV) that allows treating tumors of size up to approximately 4 mm. Its decay is followed by the emission of low-energy gamma rays suitable for SPECT imaging. Its half-life ($T_{1/2} = 61.83$ h) is optimal for human applications. Among the charged-particle-induced production routes, the ^{64}Ni$(\alpha, \mathrm{p})^{67}$Cu reaction requires much less enriched (expensive) target material for providing a comparable amount of ^{67}Cu activity as compared to proton or deuteron production routes. The available literature data are very different from each other in terms of both shape and amplitude, and only one experiment provided cross-section data above 25 MeV; therefore, we decided to investigate this production route up to 51 MeV.

Experiments were performed at the RIKEN AVF cyclotron. The stacked-foil activation technique and high-resolution γ-ray spectrometry were applied. Pure metallic foils of ^{nat}Ni and ^{nat}Ti from Nilaco Corp., Japan with an average thickness of 5 μm were used. The foils were paired (Ni-Ni, or Ti-Ti) in the stack to handle the recoil effect. Four irradiations were performed using 51.04, 49.42, 40.94, and 26.57 MeV alpha-particle beams. The incident beam energy was measured by the time-of-flight method.[1] The energy loss of the 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$(\alpha, \mathrm{x})^{51}$Cr monitor reaction.[3] After a small correction of the measured beam intensities, the re-measured cross-sections for the ^{nat}Ti$(\alpha, \mathrm{x})^{51}$Cr monitor reaction agreed perfectly with their recommended value.[3] Several series of γ-ray spectra were recorded for each irradiated foil by using a high-resolution HPGe detector-based γ-spectrometer without chemical separation for increasing cooling times to follow the decay of the reaction products. Q-values and decay data were taken from the Q-value calculator[4] and NuDat 2.7 database[5] of National Nuclear Data Center, respectively. On the ^{nat}Ni target, ^{67}Cu can be produced only in the ^{64}Ni$(\alpha, \mathrm{p})^{67}$Cu reaction with an alpha-particle beam. The threshold energy of this reaction is $E_{\mathrm{thr}} = 4.93$ MeV.

The deduced isotopic cross sections for the ^{64}Ni$(\alpha, \mathrm{p})^{67}$Cu reaction were normalized to 100% ^{64}Ni isotopic abundance. Additionally, direct and/or cumulative "elemental" activation cross-sections were deduced for the formation of ^{64,61,60}Cu, ^{63,62}Zn, and ^{57,56}Ni radionuclides as possible radio-contaminants. The obtained experimental data were compared with the experimental data available in the literature and the results of the TALYS theoretical model calculation taken from the TENDL-2019[6] data library.

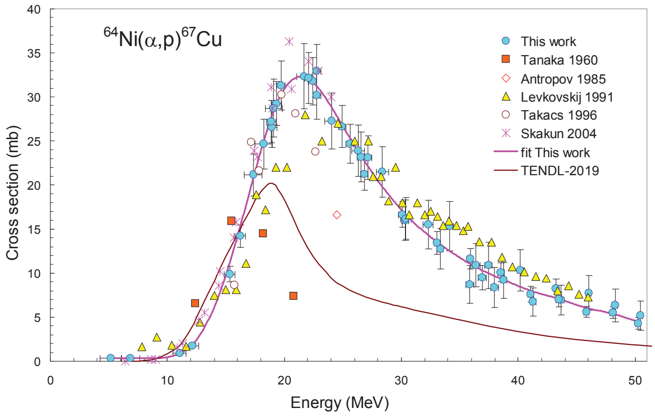

Fig. 1. Excitation function of the ^{64}Ni$(\alpha, \mathrm{p})^{67}$Cu reaction in comparison with previously reported experimental data and the result of the model calculation taken from the TENDL-2019 database.[5]

Thick target yields were calculated to estimate the expected amount of ^{67}Cu and the possible radio-contamination level of the other co-produced copper radionuclides by using the spline-fitted experimental data in the calculation. It was concluded that the production of ^{67}Cu is possible on a highly enriched ^{64}Ni target for local use only. To reduce the amount of co-produced ^{64}Cu, the bombarding alpha-particle energy should be kept below 30 MeV. During a 24 h-long (30 MeV and 30 μA) irradiation, the estimated end-of-bombardment (EOB) activity of ^{67}Cu is approximately 1 GBq, and the expected activity of the co-produced ^{64}Cu is approximately 0.15%.

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References

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