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Production Cross Sections and Isomeric Ratios for the Isomeric Pair ^{89m}Nb and ^{89g}Nb in the ^{90}Zr (d,3n) $^{89m/g}$Nb Reaction

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Abstract

This paper reports the determination of absolute excitation functions and cross section ratios for the production of $^{89m/g}$Nb in reactions of deuterons with natural zirconium.
Target stacks foils of zirconium were bombarded with beams of deuterons of 27.5 MeV.
The results are compared with the maximum cross sections estimated fi)m systematics [1–5].

Zusammenfassung

Es wird über die Bestimmung von absoluten Anregungsfunktionen, Wirkungsquerschnitten für die Bildung von $^{89m/g}$Nb bei Reaktion von Deuteronen mit Zirkon (natürliche Isotopenzusammensetzung) berichtet. Die Ergebnisse werden verglichen mit den Maximalquerschnitten, wie sie anhand der Systematik abgeschätzt wurden.

Résumé

On a déterminé les fonctions d'exitation et les proportions des sections efficaces pour la production de $^{89m/g}$Nb par irradiation de zirconium naturel par deutérons. La cible consistant d'une feuille de zirconium est bombardée par le faisceau de deutérons à 27,5 MeV. Les résultats sont comparés avec les sections efficaces maximales estimées de systématiques [1–5].

Introduction

The measurement of cross section as a function of bombarding energy combined with range energy tables will determine the maximum potencial production yield for any combination of incident particle energy, target thickness, beam current and irradiation time. The excitation function measurements are then crucial to the development of the yield of radionuclide production by charged particle bombardment.
In other way the scope of charge particle activation analysis has been expanding in recent years from a method with recognized high sensitivity measurement capability for low-Z elements to a technique of broad elemental coverage. Here also the cross-sections are necessary if the limits of detection for a given element should be calculated.
The results of the measurements of the formation cross sections of nuclear isomeric states permit determination of the isomeric cross section ratio and consequently allow an appraisal of the validity of theoretical models [6–7].

The objective of the present work was to measure the formation cross sections of isomeric states of ^{89}Nb by (d,xn) reaction on natural zirconium and the production isomeric cross section ratios [1–8].

Among the cross section determinations for charged-particle reactions [1–5], we have not found any references to the (d, 3n) reaction on zirconium.
To date only few isomeric ratios from (d,3n) reactions have been reported. VANDENBOSCH and HASKIN [9] investigated the ^{88}Sr (d,3n) $^{87m/87}$Y process with 17.8 and 20.2 MeV deuterons and DEMEYER [10] the same reaction from 20.5 to 26.5 MeV.

Experimental

a) Irradiation

Cross sections were measured by the activation method. The bombardments, were performed with the 27.5 MeV external deuteron beam of the Synchrocyclotron of the Comisión Nacional de Energía Atómica. The spread of the initial energy was estimated to be $< 1\%$.
As targets natural zirconium foils of 99.99999% purity and 13 mg/cm^2 thickness were stacked with aluminum foils of high purity to use the ^{27}Al (d,αp) ^{24}Na reaction for beam monitoring on account of its multiple known advantages [11–12].
The energy of deuterons in each target foils in the stack was determined from the tables of WILLIAMSON, BOUJOT and PICARD [13]. The energy in the middle of each foil was used as abscissa of the excitation functions. Corrections for the energy spread in each foil, due to foil thickness and energy straggling in the preceding foils, were not applied. Losses of reaction products by recoil were assumed to be negligible in the computation of the cross sections.

b) Counting

The cross sections were determined by an absolute measurement of the disintegration rates of the reaction products.
No previous chemical separation was performed.
In each foil of the stack the characteristic radiations were counted for both isomeric levels: 588 keV for ^{89m}Nb ($T_{1/2}$ = 1.1 h) and 1259 keV for ^{89g}Nb ($T_{1/2}$ = 2.03 h) and the respective activities further identified by half-lives determinations.
The photopeak intensities of the gamma rays were measured with a high resolution Ge(Li) detector and recorded on a 1024 channel pulse height analyzer.

The areas of gamma peaks observed were calculated by WASSON's method [14–15]. The corresponding efficiencies were determined experimentally and the error was estimated to be less than 5%. Decay scheme, branching ratios, half-lives values and internal conversion coefficients were taken from Nuclear Data Sheets [16] and the most recent literature [17]. These data were used to convert peak intensities to the absolute activity of each radioisotope and to calculate the production cross section for both isomers in each target foil.

Since the 1.1 h ^{89m}Nb decays entirely via the 0.588 MeV gamma ray and of the 2.03 h ^{89g}Nb 1.82 percent decays via the same gamma ray, corrections for this contribution have been made.

Results and Conclusions

The individual cross sections for the ground and isomeric states (σ_m, σ_g) and the isomeric ratios (σ_m/σ_g) are tabulated in Table 1.

The errors in the measured cross sections arise in the determination of the product nuclide activity and of the deuteron flux. The gamma-ray yield involves the photopeak counts, the photopeak efficiency of the detector, the gamma-ray transition probability, the internal conversion correction and a correction for the self-absorption in the sample. The deuteron flux involves the same quantities. The error in the flux measurements is estimated to be equal to the combined errors of these quantities. Errors in timing, weighing of the samples and in background subtraction were also estimated.

In the determination of the isomer ratios, errors in beam intensity, target thickness and target uniformity cancel. The only errors affecting these ratios are counting errors. Since for each isomer different gamma rays were used, the errors involved in the determination of counter efficiencies will not cancel but compound.

The maximum cross sections in our experimental curves were compared with those required by the systematics for excitation functions [1–5]. The agreement is good.

The isomeric ratio σ_m/σ_g decreases with the deuteron energy. In general those ratios increase with increasing bombarding energy. This is to be expected, as the angular momentum transfer increases with bombarding energy, and interactions with large angular momentum transfer should favor population of the higher spin isomer.

The decrease in the isomer ratio for our (d,3n) reaction at higher energies arises perhaps, from the increasing contribution of a direct reaction mechanism (stripping) in which the angular momentum transfer to the residual nucleus is much less than in compound nucleus reactions.

Table 1. *Cross sections and cross section ratio's for the reactions* ^{90}Zr(d,3n)^{89g}Nb *and* ^{90}Zr(d,3n)^{89m}Nb

E_d(MeV)	σ_g(mb)	σ_m(mb)	σ_m/σ_g
27.38	53.76 ± 4.9%	162.41 ± 32%	3.02 ± 32%
26.43	50.72 ± 3.9%	120.44 ± 30%	2.37 ± 30%
25.52	37.93 ± 4.8%	138.22 ± 27%	3.64 ± 27%
24.50	24.88 ± 7.5%	173.03 ± 20%	6.95 ± 22%
23.54	16.35 ± 10.3%	81.23 ± 19%	4.97 ± 21%
22.46	3.932 ± 30.8%	61.90 ± 18%	15.74 ± 36%
21.40	0.935 ± 45%		
20.25	0.710 ± 50%		

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Correction

The quotation 16. must be corrected as follows:

"16. Nuclear Data Sheets: National Academy of Sciences A, Vol. 8 (1970)."