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Rapid Communication

First Observation of γ-Ray Emission Assigned to the Decay of ^{164}W

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Summary

The excitation functions of the short-lived tungsten isotopes ^{164}W and ^{165}W produced in the nuclear reaction ^{24}Mg + ^{144}Sm were measured for E_{Lab} = 109 MeV – 141 MeV.

Two γ-lines at (187.0 ± 0.1) keV and (268.7 ± 0.2) keV were discovered in the γ-spectra of the tungsten fraction after chemical separation at a beam energy of 128 MeV which we assign to ^{164}W. The half-life of the 187.0 keV γ-line is (7.0 ± 0.2) s.

1. Introduction

Short-lived tungsten isotopes are interesting as homologues of the transactinide element 106. If these tungsten isotopes have γ-transitions, then a very convenient on-line monitoring of the chemical separation is possible if mixed rare earth and actinide targets are used for the simultaneous production of W and element 106. The half-lives of the model nuclides should be of the same order of magnitude as those of the heavy element. Presently three isotopes of element 106 with half-lives in the range of seconds are known: ^{263}106 ($T_{1/2}$ = 0.9 s) [1], ^{265}106 ($T_{1/2}$ = 2 s – 30 s) and ^{266}106 ($T_{1/2}$ = 10 s – 30 s) [2], the latter two being more suitable for chemical experiments. From this it follows that the tungsten isotopes ^{164}W ($T_{1/2}$ = 6.4 s ± 0.8 s) and ^{165}W ($T_{1/2}$ = 5.1 s ± 0.5 s) [4, 5] are best suited as model nuclei. Unfortunately, only few data on these two exotic nuclei are available from the literature. Eastham *et al.* [3] measured the excitation functions for production of $^{162/163/164}$W in the reactions $^{144/147}$Sm (^{24}Mg, xn) via α-detection. $^{165/166}$W were first produced by Toth *et al.* [4] in the reaction ^{156}Dy (^{16}O, xn). Additional data on $^{160-166}$W reported in [5, 6] were confirmed by these authors. For ^{164}W α-branches of 2.6% [5] or 5% [6] and for ^{165}W < 1.5% [5] are reported; the other decay mode is electron capture or β^+-decay. Therefore, γ-lines of these nuclides can be expected but are so far unknown.

2. Experimental

The reactions ^{24}Mg + $^{144/147/149}$Sm (85% ^{144}Sm, 15% $^{147/149}$Sm) were used to produce short-lived tungsten isotopes. The experiments were performed at the U-400 cyclotron of the Flerov-Laboratory of Nuclear Reactions at JINR in Dubna, Russia. A target of 1.0 mg/cm^2 thickness on a 20 µm Be-backing was bombarded by typically 10^{12} particles per second of ^{24}Mg^{12+} ions with a beam energy of 187 MeV. First the beam passed a vacuum window consisting of a 16 µm Al-foil. The cross-sections of $^{164/165}$W were determined at the energies 109 MeV, 115 MeV, 126 MeV, 129 MeV and 141 MeV. The beam energy was adjusted by using thin Al-degrader foils of following thicknesses: 15.0 µm, 12.2 µm, 7.5 µm, 4.7 µm, and without, respectively. The uncertainty in energy was estimated to be ±1 MeV.

The reaction products recoiling out of the target were transported from a thermalisation chamber to the chemical set-up using the NaCl/Ar gas-jet system described in [7].

First, the gas-jet passed a degasser system which was slightly modified with respect to the device described in [8]: in order to decrease the transport time from the target chamber to the detector position two instead of four filters inside the degasser were used. This decreased the chemical yield to 25%, but lowered the transport time from the production site to the detector to 20 s.

For a determination of the excitation functions the produced isotopes of W, Ta, and Hf first passed a DOWEX 50 × 8 column which retained most of the other reaction products and were then collected on a

DOWEX 1×8 column using a 0.2 M HF solution [9]. For 20 min on-line γ-detection of the anion exchange column was performed with a HPGeX detector (ORTEC); The activities of the decay products of the short-lived W isotopes, i.e. the grand-daughters ^{164}Hf (γ-line at 153.3 keV), and ^{165}Hf (γ-line at 179.9 keV), were used for a determination of the relative cross-sections.

For later half-life measurements chemical separations of tungsten were performed by adsorbing lanthanides, Ta and Hf on a DOWEX 50×8 (200−400 mesh) column saturated with $La(OH)_3$ and using a 0.1 M NaOH solution as eluent. Under these conditions the tungsten fraction passed the cation exchange column and could be adsorbed on a following DOWEX 1×8 (200−400 mesh) column. Details of the chemical set-up and the column preparation are given in [8]. With this setup it was possible to detect isotopes with half-lives down to about 5 s.

The tungsten fraction was collected on the DOWEX 1 column for each chemical separation during 45 s. Then the system was switched off and the γ-spectra were measured with a HPGeX detector positioned at the anion exchange column in 16 cycles of 1.8 s each. Between the consecutive measurements the computer system needed 0.6 s for saving the spectrum and starting the following measurement. The experiments were repeated 49 times and the corresponding spectra were summed. The anion exchange column was replaced after every experiment, whereas the cation exchange column was used for three consecutive separations and then replaced.

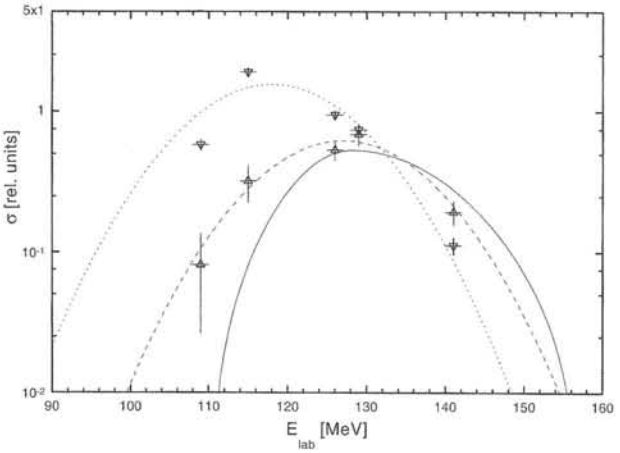

Fig. 1. Excitation functions of ^{164}W (Δ) and ^{165}W (▽) from the reaction ^{24}Mg + ^{144}Sm; the solid line is a fit through experimental data for ^{164}W from [3]; the dashed lines are to guide the eye.

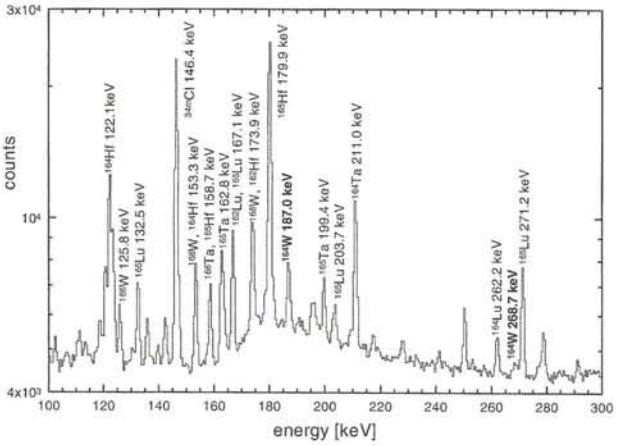

Fig. 2. γ-spectrum of a capillary-helix measurement at a beam energy of 128 MeV.

3. Results and discussion

3.1 Excitation functions

The cross-sections of ^{164}W and ^{165}W were determined via their decay products ^{164}Hf and ^{165}Hf, respectively, at beam energies between 109 MeV and 141 MeV. In this region of excitation energies ($E^* = 40-70$ MeV), based on HIVAP calculations, direct production of ^{164}Hf via the αOn-reaction and of ^{165}Hf via the 2p1n-reaction are negligible. In addition, for the α0n-channel the maximum of the excitation function is expected at about 20 MeV lower energy than the maximum of the 4n-channel which leads to ^{164}W. The production of ^{164}Ta via the p3n-reaction and of ^{165}Ta via the p2n-reactions cannot be ruled out a priori. However, these reactions would only affect the absolute values of the cross-sections and not alter the position of the maximum of the excitation functions or their shapes. Eastham *et al.* pointed out [3] that the pxn-channels peak at nearly the same energies as the (x + 1)n-channels.

For the calculations of the cross-sections growth and decay corrections were applied for the activity of the permanently collected reaction products on the anion exchange column. Only relative values for the cross section are given since the absolute intensity of the 153.3 keV γ-line of ^{164}Hf and of the 179.9 keV γ-line of ^{165}Hf are unknown as well as several yields (gas-jet transportation, chemical separation) can only be approximated.

Fig. 1, shows the results in relative cross-sections together with a fit through the experimental data from Eastham *et al.* [3] from the same nuclear reaction. Both experimental data sets for ^{164}W are in a reasonable agreement.

3.2 Search for new γ-lines

To detect possible new γ-lines of short-lived W isotopes a capillary-helix of 20 m length and 2 mm i.d. was positioned over the HPGeX detector to measure on-line and in flight the γ-spectrum of the reaction products transported with the NaCl aerosol particles.

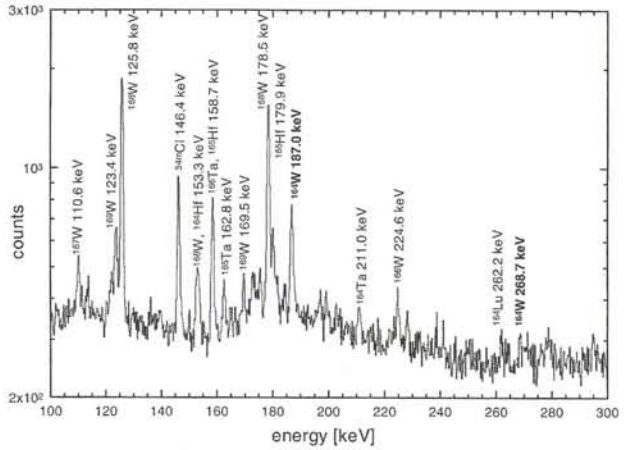

Fig. 3. Accumulated γ-spectrum of the separated tungsten fraction at a beam energy of 128 MeV.

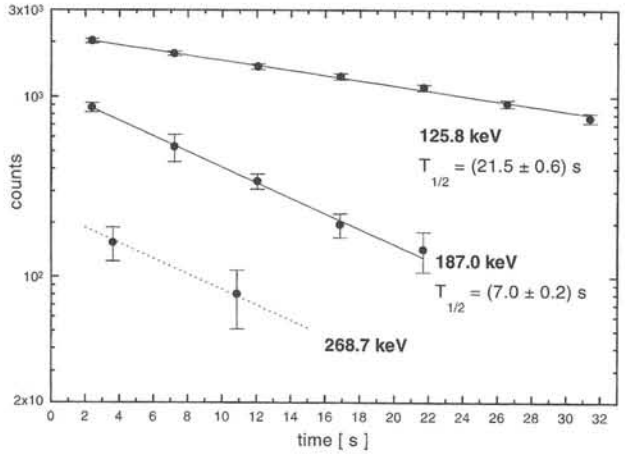

Fig. 4. Time analysis of the 125.8 keV γ-radiation from ^{166}W, and the γ-radiation at 187.0 keV and 268.7 keV assigned to ^{164}W.

Fig. 2 shows an accumulated γ-spectrum during 15 min at a beam energy of 128 MeV, which corresponds to the optimum energy for production of ^{164}Hf (Fig. 1). Two unknown γ-lines with energies of (187.0 ± 0.1) keV and (268.7 ± 0.2) keV were observed. The ratio of the activities of these two γ-lines is 5.7 ± 1.9. Since these γ-radiations might belong to short-lived tungsten isotopes we decided to perform a chemical separation prior to a decay study.

3.3 Determination of the half-life

With the chemical separation procedure described above decay measurements of the reaction products were carried out at 128 MeV.

Fig. 3 shows the accumulated γ-spectrum from all chemical separations summed up for the first 8 cycles (0 s−19.2 s) which again shows the two γ-lines at 187.0 keV and 268.7 keV. Since ^{164}W has a reported half-life of 6.4 s, an optimum binning for the time distribution of counts [13] was made by adding two consecutive spectra to generate a counting time interval of 4.8 s.

First we analysed the activity of the 125.8 keV γ-line from ^{166}W to check the counting system as well as the calculation algorithm. This yielded a half-life of (21.5 ± 0.6) s (see Fig. 4), which is in excellent agreement with (22 ± 1) s from previous work [12].

Also shown in Fig. 4 is the decay of the activity producing the two new γ-lines. The time analysis of the 187.0 keV γ-radiation yields a half-life of (7.0 ± 0.2) s. This value is in good agreement with the reported half-life of ^{164}W of (6.4 ± 0.8) s [5]. The intensity-ratio from this measurement for the 187.0 keV to the 268.7 keV γ-line is 4.2 ± 1.5, in agreement with the value from the on-line measurement.

In a previous study using the same projectile-target combination but a lower beam energy of 112 MeV these two γ-lines were not observed [8].

On the basis of the measured half-life and the knowledge of the shape of the excitation functions for ^{164}W and ^{165}W (Fig. 1), we conclude that the γ-lines at 187.0 keV and 268.7 keV are associated with the decay of ^{164}W and not with the decay of ^{165}W.

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