Supplementary information

Excited states in the nucleus ^{92}Pd were populated via ^{58}Ni(^{36}Ar,2n)^{92}Pd fusion-evaporation reactions. The ^{36}Ar ions were accelerated to an energy of 111 MeV by the CIME cyclotron, GANIL, and used to bombard target foils consisting of 99.9% isotopically enriched ^{58}Ni with an areal density of 6.0 mg/cm^2, enough to stop the fusion products. The average beam intensity was $6{\cdot}10^{10}$ ions per second (10 particle nA) during 14 days of irradiation time. Charged-particle emission following the decay of the ^{94}Pd compound nucleus was detected using the DIAMANT [1] detector system which consisted of 80 CsI scintillators. The NEUTRON WALL, comprising 50 liquid scintillator detectors [2] and covering a solid angle of 1π in the forward direction, was used for the detection of evaporated neutrons. Gamma rays emitted from the reaction products were detected using the EXOGAM [3] Ge detector system. Seven segmented clover detectors were placed at an angle of 90° and four detectors at an angle of 135° relative to the beam direction, leaving room for the NEUTRON WALL at forward angles. EXOGAM was used in a close-packed configuration with the front part of the BGO Compton suppression shields removed from the clover detectors. The trigger condition was fulfilled if one or more γ rays was registered in the Ge detectors together with at least one neutron in the NEUTRON WALL. The pulsation of the ion beam from the cyclotron accelerator provided a common time reference for the data from the different detector systems. On-line identification of neutrons used for the hardware trigger was achieved through a requirement on the zero-crossing time of the neutron detector signals. In the off-line analysis, this requirement was complemented by a second criterion applied to the time of flight of each neutron or γ ray detected in the NEUTRON WALL. The NEUTRON WALL has excellent time resolution ($\leq$ 1 ns) and the time of flight parameter can therefore be measured with a precision of the time reference of the event, which was around 3.5 ns (FWHM) given by the beam bunch structure from the CIME cyclotron. This led to a highly efficient neutron-γ separation; less than 3‰ of the detected neutrons were incorrectly identified γ rays interacting in the neutron detectors.

In total 3.9×10^9 events satisfying the trigger condition were stored on hard drives and analysed off-line. For the detected charged particles the CsI detectors give three parameters: the energy, the time and the "particle identification" (PID). The PID signals are obtained from the pulse shapes using the "ballistic deficit" method [4]. Prompt protons and alpha particles were identified by simultaneous selection criteria on these parameters. Gamma rays were required to be escape-suppressed and detected in prompt coincidence with the RF-pulse from the cyclotron. To further reduce the background originating from Compton scattered photons, the energies extracted from individual coincident pulses from the four crystals belonging to one clover were added. The resulting γ-ray energies recorded by the Ge clover detectors were sorted into two-dimensional histograms of γ-ray energies ($E_\gamma - E_\gamma$ coincidence matrices). The software package RADWARE [5] was used to establish mutual coincidences and measure relative intensities of γ rays. The clean identification of neutrons was critical in the present experiment. Neutrons scattering from one detector segment to another may be detected twice, and thus be misinterpreted as two neutrons. This gives rise to background emanating from reaction channels corresponding to only one emitted neutron in γ-ray spectra gated by two neutrons. Due to the finite velocity of the neutrons, the difference in the detection time is typically smaller for interactions resulting from two separate neutrons rather than one single scattered neutron [6, 7]. Background contributions from neutron scattering in $2n$-gated spectra could hence be reduced by applying a criterion on the difference in the time of flight parameter relative to the distance between the neutron detectors firing for events with two neutron-like interactions in the NEUTRON WALL.

The inclusion of a neutron in the trigger condition prevents the extraction of the detection efficiency for the first detected neutron from the data of the present experiment. This efficiency is typically around 25% [2]. The probability for detecting and correctly identifying the second neutron in an event with two emitted neutrons was $\approx 12\%$ when the scattering of neutrons between different detector elements was taken into account. The α particle and proton detection efficiencies were estimated to 48(2)% and 55(2)%, respectively. However, for selecting the 2-neutron-evaporation channel leading to ^{92}Pd a general "veto" condition on any charged particle detected in the CsI array was applied. The efficiency for detecting any charged particle is higher (66 %) than that for cleanly identifying individual particle types. Hence, since most reaction channels in the present experiment involve emission of more than one charged particle a higher average rejection fraction was obtained in selection of the rare 2n-evaporation events from the in total approximately four billion events dominated by the prolific charged particle emission channels. For the strongest (fusion, 2-proton,1-neutron emission) reaction channel passing the trigger condition, leading to ^{91}Ru, the rejection fraction was 87%.

The γ-ray energy spectra were examined for γ rays from the $2n$-evaporation reaction channel, corresponding to ^{92}Pd. The search was performed by comparing spectra gated by different combinations of detected particles. The γ rays from the ^{58}Ni(^{36}Ar, $2n$)^{92}Pd reaction channel can be expected to be very weak, and should not be visible in spectra gated by any other combination of detected particles. The major contaminants in the raw spectra gated by $2n$ are from the reaction channels with one or two emitted neutrons, together with one or two protons corresponding to ^{91,92}Rh [8, 9] and ^{91}Ru [10]. Gamma rays emitted in reactions involving the ^{16}O and ^{12}C target contaminants were also visible in the corresponding particle-gated spectra. Such contaminating reactions are present, since the “vacuum” in the beam line and the target chamber is not ideal and the cross sections for (fusion, neutron-evaporation) reactions involving these nuclides are large compared with that of the reaction channel of interest.

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