

IDENTIFICATION OF THE DOUBLY-MAGIC NUCLEUS ^{100}Sn IN THE REACTION $^{112}\text{Sn}(63 \text{ MeV/NUCLEON}) + ^{\text{nat}}\text{Ni}$

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We report on the production of the doubly-magic nucleus ^{100}Sn and other proton-rich nuclei in the $A = 100$ region in the reaction $^{112}\text{Sn} + ^{\text{nat}}\text{Ni}$ at 63 MeV/nucleon. The experiment was carried out using the high acceptance device SISSI and the Alpha and LISE3 spectrometers at GANIL. The identification of the reaction products (A , Z and Q) was made using the measurements of time-of-flight, energy-loss and kinetic energy.

The investigation has been performed by an international collaboration of scientists from FLNR, JINR (Dubna), GANIL (Caen), Warsaw University, IPN (Orsay).

Идентификация дважды магического ядра ^{100}Sn
в реакции $^{112}\text{Sn}(63 \text{ МэВ/нуклон}) + ^{\text{nat}}\text{Ni}$

М.Левитович и др.

Представлены результаты по получению дважды магического ядра ^{100}Sn и других протонно-обогащенных ядер в области $A = 100$ в реакции $^{112}\text{Sn}(63 \text{ МэВ/А} + ^{\text{nat}}\text{Ni})$. Эксперимент проводился с использованием ус-

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тановки с высоким акцептансом SISSI и спектрометров ALPHA и LISE3 (GANIL). Идентификация продуктов реакции по A , Z и Q проводилась путем измерения их времени пролета, потерь энергии и кинетических энергий.

Работа выполнена в международном сотрудничестве ученых из ФЛЯР ОИЯИ (Дубна), ГАНИЛ (Кан), Университет (Варшава), ИЯФ (Орсе).

1. Introduction

Studies of $N = Z$ and neighbouring nuclei, especially in the region of a double shell closure, are important for the testing and further development of nuclear models [1,2]. In particular, these studies provide information about the interaction between protons and neutrons occupying the same shell-model orbits.

While $N = Z$ nuclides of low mass are mostly stable, the heavier ones lie away from the line of beta stability. In the case of ^{100}Sn , the deficit of neutrons with respect to the mean atomic mass of the stable tin isotopes is about 18 and it is expected [3] to be the heaviest $N = Z$ nuclear stable against ground-state proton decay. This stability is related to the doubly-magic character of ^{100}Sn . It may be noted that for heavier $N = Z$ nuclei the condition of double shell closure is not sufficient to ensure stability: ^{164}Pb presumably lies well beyond the proton drip line. Mapping the proton-drip line in the neighbourhood of ^{100}Sn may also be of great importance in an astrophysical context as the properties of the proton-rich nuclei dictate the pathway of the rapid proton capture process in hot, dense stellar environments [4].

Beta decay in the ^{100}Sn region can be described in a very simple shell-model picture. It is strongly dominated by one channel, the $\pi g_{9/2} \rightarrow \nu g_{7/2}$ Gamow-Teller (GT) transition, and thus the observation of fast beta decays can lead to the unambiguous identification of the parent and daughter nuclear states. A meaningful verification of model predictions can be performed as, due to the high Q_{EC} values, the beta decay strength can be determined over a large energy range [5]. This had been a motivation for a series of experiments using on-line mass separators at GSI Darmstadt, LLN IKS Leuven and CERN/ISOLDE Geneva [1].

The nuclei ^{100}In ($T_{1/2} = 5 \pm 1$ s) and ^{101}Sn are the closest ones to ^{100}Sn discovered so far using a fusion-evaporation reaction ($^{58}\text{Ni}(5 \text{ MeV/nucleon}) + ^{50}\text{Cr}$) and the on-line mass-separation technique

[6,7]. These nuclei were identified via the measurement of beta-delayed protons, a decay mode which becomes energetically possible in this region due to the high Q_{EC} . However, any attempt to produce and identify in the same way ^{100}Sn is most probably hopeless. Indeed, for ^{101}Sn approximately one proton was observed per hour, for the proton branching ratio that is predicted to be larger than 10%. The production rate and the proton branching ratio in the case of ^{100}Sn are expected to be at least one and several orders of magnitude lower respectively. Obviously other production methods and identification techniques have to be used to reach and study ^{100}Sn [8]. The expected increase of the production yields is mainly due to the use of ^{112}Sn as a projectile. This rare primary beam is developed at GANIL in a close and already very fruitful collaboration with the Laboratory of Nuclear Reactions, JINR at Dubna.

Recently, in April 1994, ^{100}Sn was identified in projectile-fragment separator based experiments. In this letter we report on the work performed at GANIL using a 63 MeV/nucleon ^{112}Sn beam [9,10]. The experiment carried out at GSI with a 1.1 GeV/nucleon ^{124}Xe beam is described in ref. [11].

To produce and identify ^{100}Sn at GANIL a fragmentation-like reaction was employed in conjunction with the new SISSI device [12] and the magnetic spectrometers Alpha [13] and LISE3 [14] which provided for the collection, separation and in-flight identification of the different reaction products. In order to enhance the production of neutron-deficient isotopes a beam of the lightest, stable tin isotope, ^{112}Sn , and a natural Ni target (68.3% ^{58}Ni) were used. In an earlier experiment [9], we had already observed the neutron deficient tin isotopes down to ^{101}Sn , including the previously unknown ^{102}Sn . In addition, new isotopes of rhodium (^{92}Rh , ^{93}Rh) and palladium (^{93}Pd) were clearly observed and evidence for the production of even lighter isotopes of these elements, such as ^{91}Rh , ^{90}Rh , ^{89}Rh and ^{92}Pd , was also obtained (identification of these neutron-deficient rhodium and palladium isotopes has been very recently reported by a group working at MSU [15]). The present experiment, performed with a substantially enhanced experimental arrangement provided a confirmation of these results and the discovery of several new nuclides, including ^{100}Sn . Here we present the evidence for ^{100}Sn while the entire data set (e.g. the evidence for

^{105}Sb and the new isotope ^{104}Sb) will be the subject of a forthcoming publication.

2. Identification of ^{100}Sn and Neighbouring Nuclei

The experimental set-up for the identification of ^{100}Sn and neighbouring nuclei is shown in figure 1. The production target was located between the two superconducting solenoids of SSSI. Thus, in comparison with the previous experiment [9] the angular acceptance for the reaction products was increased by an order of magnitude and the flight-path (118m in the present experiment) increased by almost a factor of 3. The momentum analysis was performed using the Alpha spectrometer ($B\rho = 1.876\text{ Tm}$) with an acceptance $\Delta p/p = \pm 0.29\%$.

To reduce the rate of the light, fully stripped fragments arriving at the final focus of LISE3 with $A/Z \approx 2$, a thin mylar foil ($1.5\mu\text{m}$) was placed at

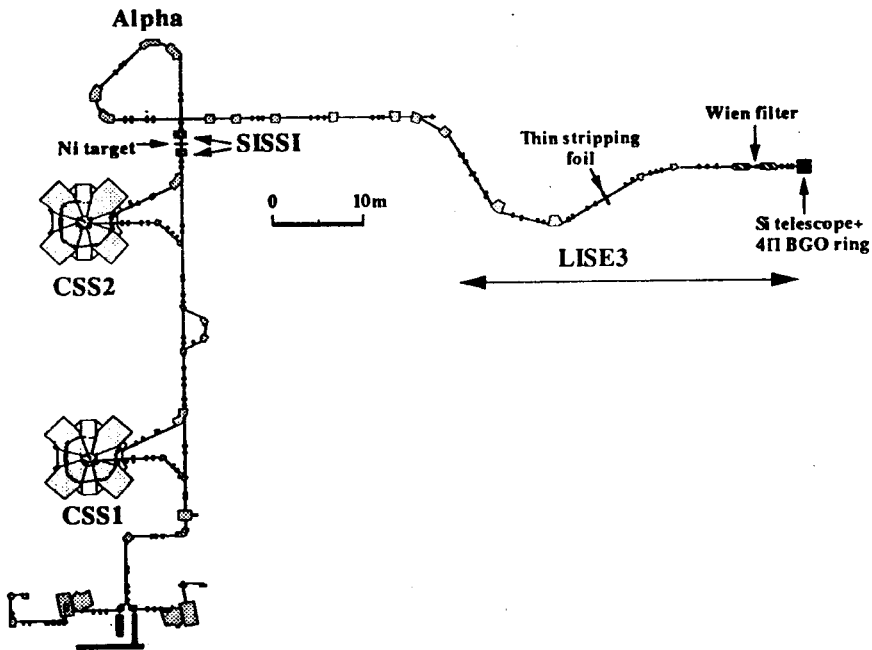


Fig.1. Schematic diagram of the experimental facilities at GANIL used to produce and identify ^{100}Sn

the intermediate focal plane (see figure 1). The function of this foil was to change the charge state distributions of the heavy fragments without modifying the velocities. For example, $^{100}\text{Sn}^{+48}$ was converted into a mixture of $^{100}\text{Sn}^{+49}$, $^{100}\text{Sn}^{+48}$ and $^{100}\text{Sn}^{+47}$ (the charge state $Q = +48$ was the most strongly populated after the target and stripping foil for the tin isotopes). Light fragments, however, remained fully stripped. Consequently, by employing an acceptance range in the second section of LISE3 from $1.013 \times B\rho$ to $1.063 \times B\rho$, the transmission of fully stripped ions was strongly suppressed and that of the nuclei in the region of interest was favoured. The number of unwanted particles was further reduced using the velocity filter located at the end of LISE3.

Fragments arriving at the final focus of LISE3 were stopped in a telescope consisting of four silicon detectors: $E1(300\mu\text{m})$, $E2(300\mu\text{m})$, $E3(300\mu\text{m})$ and $E4(500\mu\text{m})$. Since ions in the mass region of interest were stopped in the $E2$ detector, the $E1$ detector provided information on the energy-loss (ΔE), while the $E1$ and $E2$ detectors combined served to determine the total kinetic energy (TKE). The $E3$ and $E4$ detectors were used in veto to reject events corresponding to lighter ions. The time-of-flight (TOF) was measured using a start signal provided by the first Si detector ($E1$) and a stop signal derived from the radio-frequency of the second cyclotron. Finally, a segmented BGO ring [16] surrounding the implantation telescope was used for the detection of prompt gamma-rays in order to reject events corresponding to reactions in the detectors.

The Ni target (144 mg/cm^2) was mounted such that the angle with respect to the beam axis could be changed from 0° to 45° . Angles between 36° and 45° were used to allow the transmission of ^{112}Sn ions with $Q = +46$ to $+50$ to the Si detector telescope in order to provide calibrations for the energy-loss, total kinetic energy and time-of-flight measurements. It should be noted that the magnetic rigidity of the beam line from the production target to the stripping foil remained fixed during the whole experiment at 1.876 Tm . This corresponded to the maximum calculated production rate for $^{100}\text{Sn}^{+48}$ ions.

The transmission of the beam line from the exit of the Alpha spectrometer to the final focus of LISE3 was measured using movable $300 \mu\text{m}$ Si detectors located at the exit of the Alpha spectrometer, at the entrance to and at the intermediate focal plane of LISE3 and using the Si detector telescope. A transmission of nearly 100% was found.

The resolution (FWHM) of the TOF measurement was about 1 ns, while the TOF ranged from 1.4 to $1.5 \mu\text{s}$. The atomic number of the fragments (Z) was calculated using the ΔE measured with $E1$ detector and absolute Z

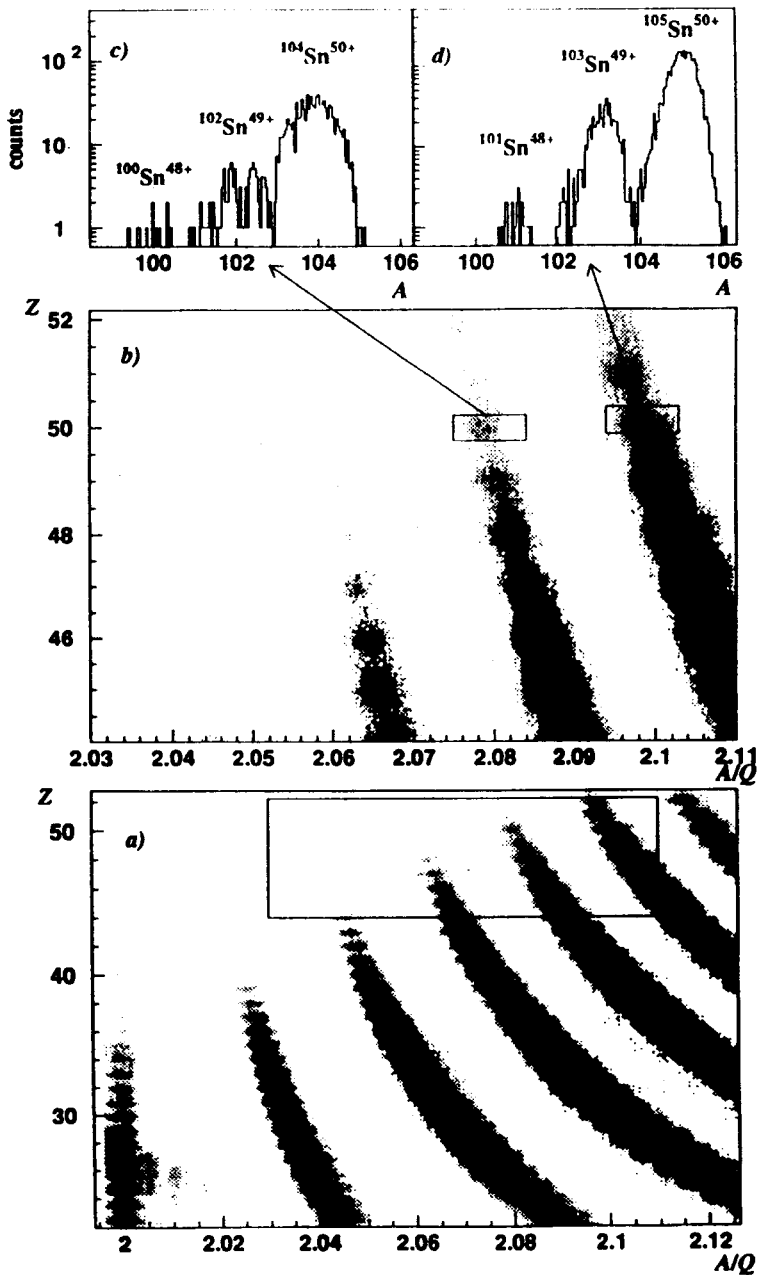


Fig.2. Identification of the reaction products: a) atomic number (Z) versus mass-to-charge ratio (A/Q); b) region of plot a) with two groups of tin isotopes indicated for which mass (A) distributions have been calculated as shown in panels c) and d). The charge states indicated correspond to those before the stripping foil (see text)

identification was obtained from the charge states of ^{112}Sn primary beam [9]. Another unambiguous assignment of the Z was obtained from the direct identification of the light ions in the ΔE versus TOF spectrum. In figures 2a and b the mass to charge ratio, A/Q , determined from the $B\rho$ and measured TOF is displayed versus Z for the nuclei in the region of interest.

It is possible to calculate for a group of events selected on the basis of the Z and A/Q (figure 2), the masses of the individual ions from the measured TKE and TOF [9]. The resulting mass distributions for $^{104}\text{Sn}^{+50}$, $^{102}\text{Sn}^{+49}$, $^{100}\text{Sn}^{+48}$ and $^{105}\text{Sn}^{+50}$, $^{103}\text{Sn}^{+49}$, $^{101}\text{Sn}^{+48}$ are given in figures 2c and d respectively. Eleven events corresponding to $^{100}\text{Sn}^{+48}$ were observed over a period of 44 hours a primary beam intensity of ~ 2.4 pA. The relative yields of the different isotopes of tin shown in figure 2 do not reflect the corresponding production cross-sections as they are affected by the distribution of the products over the different charge states as well as the different transmission efficiencies.

The number of events observed may be used to obtain a lower limit for the production cross-section by taking into account the estimated transmission efficiency ($\sim 5\%$) and the charge state distribution measured for the ^{112}Sn beam after the Ni target. For ^{100}Sn this leads to $\sigma \geq 120$ pb.

At present, the time correlations for 511—511 keV gamma-ray pairs recorded in opposite segments of the BGO ring, in coincidence with heavy fragments implanted in the telescope, have not been analyzed. However, the production rates are promising for future half-life and mass measurements.

3. Summary

For the first time nuclei near and at the proton drip-line in the region of the doubly-magic nucleus ^{100}Sn have been produced with relatively high rates — about 5 per day for ^{100}Sn . This result confirms that medium energy fragmentation-like reactions combined with projectile-fragment separation techniques presently offer the most efficient method for the production of very neutron-deficient nuclei up to $A \approx 100$.

As a much higher intensity primary beam and a larger momentum acceptance for the Alpha spectrometer are available; an increase in the production rate of ^{100}Sn by at least a factor of 5 seems feasible.

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