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ABSTRACT

Using $^{58}Ni + ^{50}Cr$ and $^{58}Ni + ^{54}Fe$ reactions and on-line mass separation, the new isotopes ^{103}Sn and ^{105}Sn with half-lives of 7 ± 3 s and 31 ± 6 s, respectively, were identified via their beta-delayed proton decays. The relative yields and the possibility of reaching ^{101}Sn are discussed.

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1. Introduction

In order to approach experimentally the doubly-magic nucleus $^{100}_{50}Sn$, heavy-ion induced fusion-evaporation reactions appear to be the most suitable production mechanism at present. However, far away from beta stability the production cross sections and, correspondingly, the number of atoms available for investigations become very low. This represents a problem for a detailed spectroscopy necessary for gaining information on nuclear-structure properties, e.g. for measuring the mass-excess or for investigating excited levels.

Another motivation for investigations in this region, and a more realistic one than the attempt to reach ^{100}Sn, is to extend the series of $T_z = 1/2$ and $T_z = 3/2$ beta-delayed proton precursors /1/, ^{97}Cd /2/ being the heaviest member observed so far for the $T_z = 1/2$ series, ^{95m}Pd /3/ and ^{99}Cd /2/ being the only known $T_z = 3/2$ precursors.

In this work we present the identification of two new neutron-deficient isotopes of tin, which are beta-delayed proton precursors, and discuss the results in view of reaching even lighter tin isotopes.

2. Experimental Techniques

On the basis of production cross-sections calculated using the HIVAP code /4/ (see Fig. 1), fusion reactions between ^{58}Ni projectiles and ^{50}Cr or ^{54}Fe targets seem to be

favourable for the production of light tin isotopes. We used ^{58}Ni beams from the UNILAC with energies of 290 MeV and intensities of about 20 particle-nA. The target thicknesses were 3.5 mg/cm^2 for ^{50}Cr and 4.0 mg/cm^2 for ^{54}Fe. Under these conditions, the evaporation code predicts cross-sections of the order of 1 mb for the production of ^{103}Sn and 30 mb for the production of ^{105}Sn.

In order to enable nuclide assignment in spite of the broad cross-section distribution, we applied on-line mass separation /5/ using a FEBIAD ion source /6/ with a graphite catcher and investigated the proton radioactivity at mass 105, 103 and 101 simultaneously. While e.g. the mass-103 activity was collected by a moving-tape system equipped with a telescope detector, the mass-101 and mass-105 beams were implanted into 10 μg/cm^2 thick carbon collectors in front of "in-beam" telescope detectors (ΔE: 25-30 μm, 150 mm^2; E: 676-732 μm, 450 mm^2; solid angle 12-22% of 4π sr). Energy spectra for beta-delayed protons were generated as coincident sum between pulses from the ΔE and E detectors. Time analyses were performed on the decay of the mass-103 activity at the tape station and on the grow-in decay pattern resulting from periodically deflecting the mass-105 beam at the in-beam telescope position.

3. Experimental Results

The energy spectra of beta-delayed protons measured at mass 105 and 103 and assigned to the precursors ^{105}Sn and ^{103}Sn, respectively, are shown in Figs. 2 and 3 together with half-life analyses. Data were accumulated both from the ^{50}Cr and the ^{54}Fe target with about 1.4 h counting time for each. The counting rates for ^{105}Sn and ^{103}Sn amounted to 3.3 min^{-1} and 1.0 min^{-1}, respectively, for the ^{50}Cr target, whereas the source strengths normalized to the same ^{58}Ni beam current were higher by 10% and lower by a factor of 2, respectively, for the ^{54}Fe target. Fifteen beta-delayed proton events were found for mass 101 by measuring this activity at an in-beam telescope detector simultaneously to the epxeriments mentioned above.

As far as the assignment of the observed beta-delayed proton activities to ^{105}Sn and ^{103}Sn is concerned, the mass number is given unambiguously by the magnetic separation. Higher-Z isobaric nuclei are excluded on the basis of systematics for production cross sections and/or of energy systematics for beta-delayed proton emission. The elemental assignment with respect to lower-Z isobaric nuclei is easily made since their known half-lives /7/ differ distinctly from the values of 31 ± 6 s and 7 ± 3 s measured for ^{105}Sn and ^{103}Sn, respectively. The few proton events observed at mass 101 cannot yet be assigned with certainty to the decay of ^{101}Sn, even though this assignment is the most probable one. More experimental data, in particular on the half-lives of ^{101}Sn and ^{101}In, are needed to clarify the present ambiguity.

4. Discussion

The measured beta-delayed proton data can be compared with results from calculations using a statistical model /8,9/. Ground-state spin and parity I^{π} of $5/2^{+}$ for the initial nuclei and a constant beta-strength function were assumed. Using recent mass measurements /10/ and extrapolating the trend of their deviations from model-predictions, we obtained values of Q_{EC}/S_{p} (in MeV) for the precursors ^{105}Sn, ^{103}Sn and ^{101}Sn of 5.98/2.79, 7.39/2.04 and 8.65/1.27, respectively. It is interesting to note that the $Q_{EC}-S_{p}$ value was known from mass measurements /10/ to be 3.19 ± 0.13 keV for the precursor ^{105}Sn (see fig. 2) prior to its identification. The calculations of the beta-delayed proton spectra can at present only be considered as a first approximation, and more complete experimental data such as better statistics in the proton spectra and branching ratios for the total beta-delayed proton decay and its feeding of excited states in the final cadmium nuclei are clearly needed. The measured gross shape of the beta-delayed proton spectra, including the overall shift towards higher proton energies in going from ^{105}Sn to ^{103}Sn, is reproduced by the model calculations. In judging the measured energy spectra one should take into account, that there is a detection threshold in the energy range of 1.5 to 2 MeV corresponding to the stopping of protons in the ΔE detector. As far as beta decay is concerned, it is interesting to notice the qualitative agreement between the half-lives measured for ^{103}Sn and ^{105}Sn and the values of 5 s and 30 s, respectively, predicted by the gross theory of beta decay /11/.

In comparing the proton rates measured for the ^{50}Cr and ^{54}Fe targets with results from evaporation calculations (see Fig. 1), one notes that at least the trends in producing ^{103}Sn and ^{105}Sn are correctly described by the code within a factor of 2. Quantitative conclusions are excluded at present as an experimental production cross section could only be determined from our measurements if the on-line overall efficiencies and the branching ratios for beta-delayed proton emission were known. Qualitatively, however, one can use calculated production cross sections, measured proton rates and calculated branching ratios P_p for beta-delayed proton emission in order to derive overall efficiencies η (see table 1). As the resulting η values and their dependence on half-life are in accordance with the general trend emerging from earlier measurements /6,12/, the evaporation code and the beta-delayed proton calculations taken together seem to give a proper description. The difficulty in studying even more neutron-deficient tin isotopes such as the doubly magic nucleus $^{100}_{50}$Sn becomes evident considering the cross section of about 8 μb calculated for the production of ^{101}Sn in the ^{50}Cr(^{58}Ni,2p5n) reaction.

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Precursor	Half-life (s)		$\eta \times P_p$	P_p from statistical model calculations	η
	measured	calculated /11/			
^{105}Sn	31 ± 6	30	6×10^{-6}	1.4×10^{-4}	4×10^{-2}
^{103}Sn	7 ± 3	5	6×10^{-5}	8.7×10^{-3}	7×10^{-3}
^{101}Sn	-	1	$\sim 2 \times 10^{-4}$	9.3×10^{-3}	$\sim 2 \times 10^{-3}$

Table 1. Compilation of beta-delayed proton data for the precursors ^{105}Sn, ^{103}Sn and ^{101}Sn. The product betweeen on-line overall efficiency η and beta-delayed proton branching ratio P_p is obtained by comparing measured proton activities with primary production rates, the latter being determined by target thickness, ^{58}Ni-beam intensity and calculated cross sections. Using the calculated P_p values one obtains the overall efficiencies given in the last column.

Figure captions

Fig. 1. Excitation functions of fusion-evaporation cross-sections calculated for a 4 mg/cm^2 thick ^{54}Fe target and a 3.5 mg/cm^2 thick ^{50}Cr target using the HIVAP code /4/.

Fig. 2. Energy spectrum of beta-delayed protons from the precursor ^{105}Sn, produced in ^{58}Ni + ^{54}Fe and ^{58}Ni + ^{50}Cr reactions and measured by an in-beam telescope detector with the mass-105 beam chopped into 50-s collection and 50-s decay intervals. The grow-in decay pattern shown as inset contains experimental data (open points) and results from a least squares fit (solid curve) yielding the indicated half-life. The arrow marks the known end-point energy.

Fig. 3. Energy spectrum of beta-delayed protons from the precursor ^{103}Sn, produced in ^{58}Ni + ^{50}Cr reactions and measured by an in-beam telescope detector. The decay pattern shown as inset contains experimental data (open points) from a telescope measurement in the counting position of a tape transport system operated with a collection time of 10 s, and includes also results from a least-squares fit (solid curve) yielding the indicated half-life.

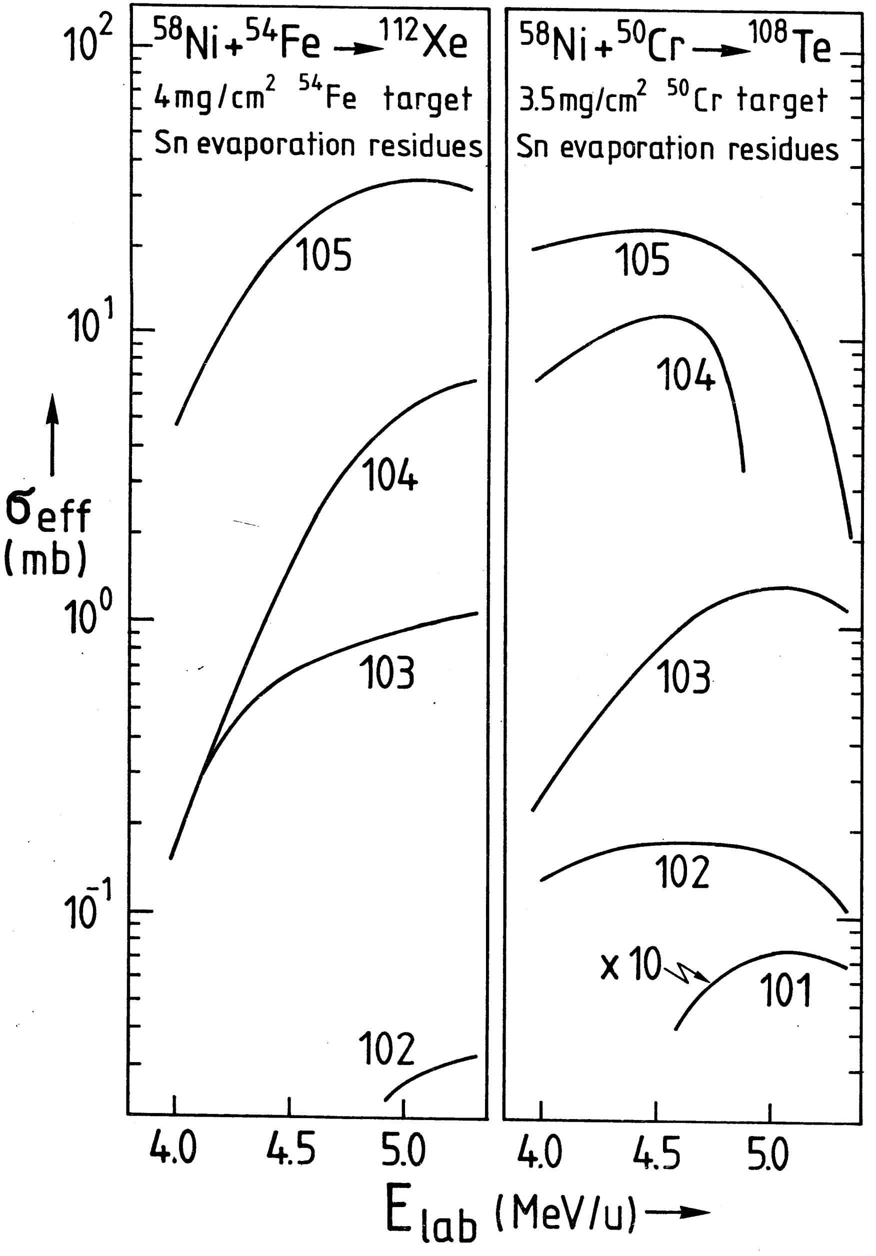
$^{58}Ni + ^{54}Fe \rightarrow ^{112}Xe$
4mg/cm^2 ^{54}Fe target
Sn evaporation residues
$^{58}Ni + ^{50}Cr \rightarrow ^{108}Te$
3.5mg/cm^2 ^{50}Cr target
Sn evaporation residues
10^2
10^1
10^0
10^{-1}
σ_{eff} (mb)
105
104
103
102
101
x 10
4.0
4.5
5.0
E_{lab} (MeV/u)

Fig. 1

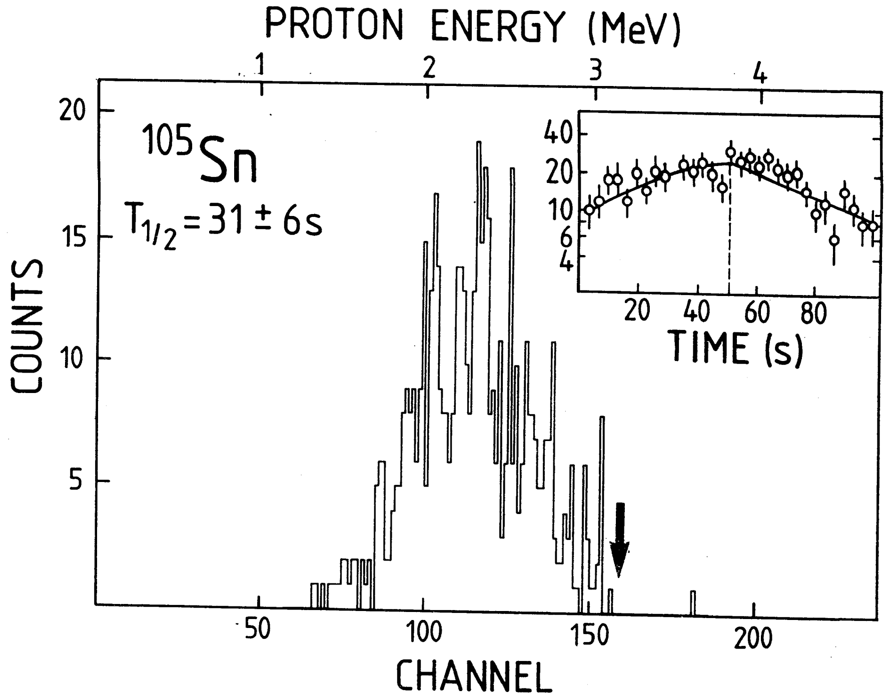
PROTON ENERGY (MeV)
1
2
3
4
^{105}Sn
$T_{1/2} = 31 \pm 6s$
COUNTS
20
15
10
5
50
100
150
200
CHANNEL
40
20
10
6
4
20
40
60
80
TIME (s)

Fig. 2

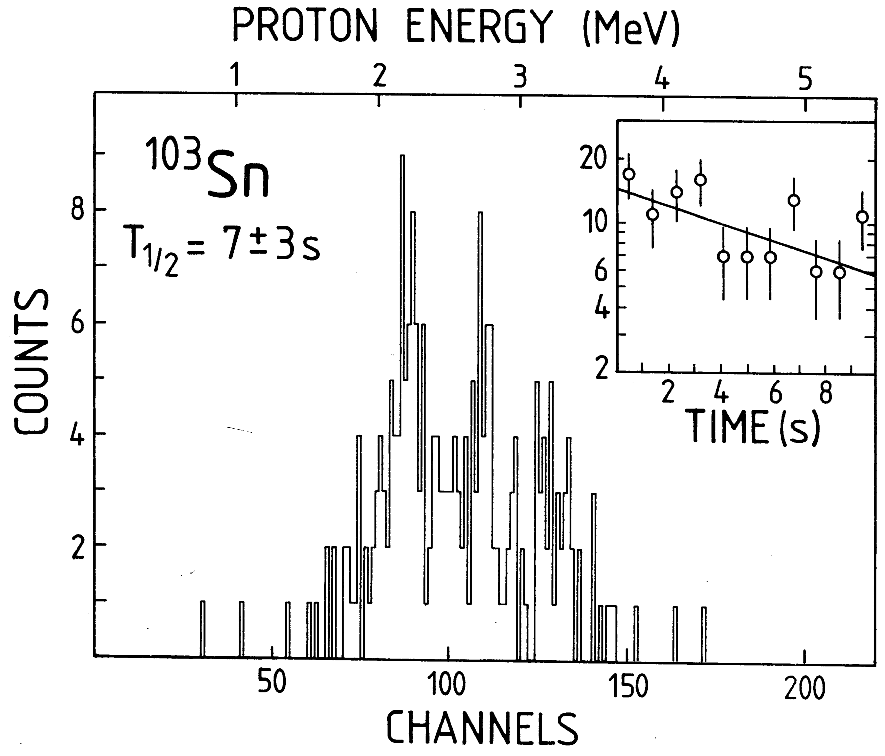
PROTON ENERGY (MeV)
1
2
3
4
5
^{103}Sn
$T_{1/2} = 7 \pm 3$s
COUNTS
2
4
6
8
50
100
150
200
CHANNELS
20
10
6
4
2
2
4
6
8
TIME (s)

Fig. 3