FR9700873

IDENTIFICATION OF ^{100}Sn AND OTHER PROTON DRIP-LINE NUCLEI IN THE REACTION ^{112}Sn + ^{nat}Ni AT 63 MeV/nucleon

M. Lewitowicz[a], R. Anne[a], G. Auger[a], D. Bazin[a], C. Borcea [b], V. Borrel[c], J.M. Corre[a], T. Dörfler[d], A. Fomichov[e], R. Grzywacz[f], D. Guillemaud-Mueller[c], R. Huc[a], M. Huyse[g], Z. Janas[h],*, H. Keller[h], S. Lukyanov[e], A.C. Mueller[c], Yu. Penionzhkevich[e], M.Pfützner[f], F. Pougheon[c], K. Rykaczewski[f], M.G. Saint-Laurent[a], K. Schmidt[h], W.D. Schmidt-Ott[d], O. Sorlin[c], J. Szerypo[g],*, O. Tarasov [e], J. Wauters[g], J. Żylicz[f]

[a] *GANIL, BP 5027,14021 Caen Cedex, France*
[b] *IAP, Bucharest-Magurele P.O.Box MG6, Roumania*
[c] *IPN, 91406, Orsay Cedex, France*
[d] *University of Göttingen, D-3400, Göttingen, Germany*
[e] *FLNR, JINR 141980 Dubna, Moscow region, Russia*
[f] *IFD, Warsaw University, 00681 Warsaw, Poland*
[g] *IKS KU, B-3001, Leuven, Belgium*
[h] *GSI, Postfach 110552, D-64220, Darmstadt, Germany*

Abstract

The doubly-magic nucleus ^{100}Sn and six new neutron-deficient nuclei in the A$\sim$100 region were identified in the reaction ^{112}Sn + ^{nat}Ni at 63MeV/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.

Studies of N=Z and neighbouring nuclei, especially in the region of a double shell closure, are important for 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 system 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

*On leave of absence from IFD, Warsaw University, 00681 Warsaw, Poland 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 and 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}Ni (5 MeV/nucleon) + ^{50}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 a 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].

Recently, in April 1994, ^{100}Sn was independently identified in two experiments employing a projectile-fragment separator technique. Here we report on the work performed at GANIL using a 63MeV/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 SISSI device [15] and the magnetic spectrometers Alpha [16] and LISE3 [17] 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 recently reported by a group working at MSU [18]). The present experiment, performed with a substantially enhanced experimental arrangement provided a confirmation of these results and the discovery of several new nuclides, ^{100}Sn,^{103}Sb,^{104}Sb,^{98}In, ^{91}Pd,^{89}Rh and ^{87}Ru [12, 13].

The experimental set-up used 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 SISSI. 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 Tm) with an acceptance $\Delta p/p$=0.29 %. To reduce the rate of the light, fully stripped fragments arriving at the final focus of LISE3 with A/Z≈2, a thin mylar foil (1.5μm) was placed at 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 their velocities. For example, $^{100}Sn^{+48}$ was converted into a mixture of $^{100}Sn^{+49}$, $^{100}Sn^{+48}$ and $^{100}Sn^{+47}$ (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×$B\rho$ to 1.063×$B\rho$, 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 (300μm),E2 (300μm), E3 (300μm) and E4 (500μm). 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 mode 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.
The Ge detector array surrounding the implantation telescope used in the first experiment with the ^{112}Sn beam was replaced by a segmented BGO ring [19]. An increase in efficiency (from 6.4% to 50% for the 511 keV photopeak) was preferred to the good resolution. The priority of the gamma-detection was the recording of annihilation radiation (the 511-511 keV pairs in opposite segments) in correlation with heavy-ions, in order to obtain half-life information on the exotic nuclei. However, even with the poor resolution of the BGO ring, nine known decays of the short-lived isomeric states (from ^{43m}Sc to ^{96m}Pd) were clearly observed [14]. This confirmed unambiguously the standard ΔE-TKE-TOF isotope identification procedure, which was based on the calibrations with ^{112}Sn charge states.
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 $^{100}Sn^{+48}$ 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 μm Si detectors located at the exit of the Alpha spectometer, 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 μs. The atomic number of the fragments (Z) was calculated using the ΔE measured with the E1 detector and absolute Z identification was obtained from the charge

states of ^{112}Sn primary beam [20, 9]. Another unambiguous assignment of Z was obtained from the direct identification of the light ions in the ΔE versus TOF spectrum.
From the measured TKE and TOF [20, 9] for a group of events, selected on the basis of the Z and A/Q (figure 2) it is possible to calculate the masses of the individual ions . The resulting mass distributions for $^{104}Sn^{+50}$, $^{102}Sn^{+49}$, $^{100}Sn^{+48}$ and $^{105}Sn^{+50}$, $^{103}Sn^{+49}$, $^{101}Sn^{+48}$ are given in figures 2*c* and *d* respectively. Eleven events corresponding to $^{100}Sn^{+48}$ were observed over a period of 44 hours with a primary beam intensity of ~2.4 pnA. 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 events attributed to the same fragment but produced in the different charge states Q at the target have been summed up. For even-mass nuclei the charge states corresponding to A-2Q=4 (e.g. $^{100}Sn^{+48}$) and A-2Q=6 (e.g. $^{100}Sn^{+47}$) have been taken into account, while for odd-masses A-2Q=3 (e.g. $^{101}Sn^{+49}$) and A-2Q=5 (e.g. $^{101}Sn^{+48}$) were included. The distributions of even- and odd-mass nuclei are presented in the separate pictures of Fig. 2 - as they were observed at the two-dimensional Z versus A/Q plot, see [12]. In these mass-spectra the respective neighbouring nuclei (with ΔA=2) are clearly separated. In addition to the eleven events of $^{100}Sn^{+48}$ reported in [12], thirteen more events have been assigned to the $^{100}Sn^{+47}$ ions, giving a total of 24 events of ^{100}Sn identified in this experiment.
The obtained data allow for the identification of six other new nuclei, namely ^{103}Sb, ^{104}Sb, ^{98}In, ^{91}Pd, ^{89}Rh and ^{87}Ru, which are clearly isolated from neighbouring heavier isotopes in the measured spectra given in Fig. 3.
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 (~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.
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≈100.

References

[1] K. Rykaczewski, Proc. of 6th Int. Conf. on Nuclei far from Stability and 9th Int. Conf. on Atomic Masses and Fundamental Constants, Bernkastel-Kues 1992, R. Neugarth, A. Wöhr (eds), IOP Conf. Ser. **132** (1993) 517

[2] A. Johnson et al., Nucl. Phys. A557 (1993) 401c

[3] P.E. Haustein (ed.), At. Data Nucl. Data Tables **39** (1988) 185

[4] R.K. Wallace and S.E. Woosley, Astrophys.J.Suppl. **45** (1981) 389

[5] B.A. Brown and K. Rykaczewski, Phys.Rev. C **50**, R2270

[6] J. Szerypo et al., Nucl. Phys. **A584** (1995) 221

[7] E. Roeckl, GSI-Nachrichten 09-93 (1993) 3

[8] R. Anne et al, "Towards the study of Gamow-Teller beta decay of ^{100}Sn", proposal to the GANIL Comite d'Experiences, June 1993, Ganil Report 93 06, p.70

[9] M. Lewitowicz et al., Nouvelles du Ganil **48** (1993) 7

[10] M. Lewitowicz et al., Nouvelles du Ganil **50** (1994) 3

[11] R. Schneider et al., Z.Phys.A **348** (1994) 241

[12] M. Lewitowicz et al., Phys. Lett. **B332** (1994) 20

[13] K. Rykaczewski et al., Phys. Rev. C **52** (1995) R2310

[14] R. Grzywacz et al., Phys. Lett. **B355** (1995) 439

[15] A.Joubert et al., Proc. of the Second Conf. of the IEEE Particle Accelerator, San Francisco, May 1991, p.594 and SISSI, Nuclear Physics News, Vol.1, N° 2, 1990, p.30

[16] R. Rebmeister et al., Report CRN/PN 1983-16, 1983

[17] R. Anne and A.C.Mueller, Nucl. Instr. and Meth. B70 (1992) 276

[18] M. Hencheck et al., Phys. Rev. C **50** (1994) 2219

[19] H. Keller et al., Z.Phys.A **340** (1991) 363

[20] D. Bazin et al., Nucl. Phys. **A515** (1990) 349

Figure Captions

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

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 foli (see text).

3 Mass distributions separated into odd-A and even-A quasi-fragmentation products observed in the experiment with the ^{112}Sn beam at 63 MeV/nucleon: (a) for Z from 52 to 48, (b) for Z from 47 to 44. Nuclei identified for the first time in this study are indicated by solid arrows, while the events assigned to ^{100}Sn and ^{106}Te (discussed in the text) are marked by dashed arrows. The number of counts corresponds to the 2.4×10^{15} incident particles on the ^{nat}Ni (144 mg/cm^2) target.

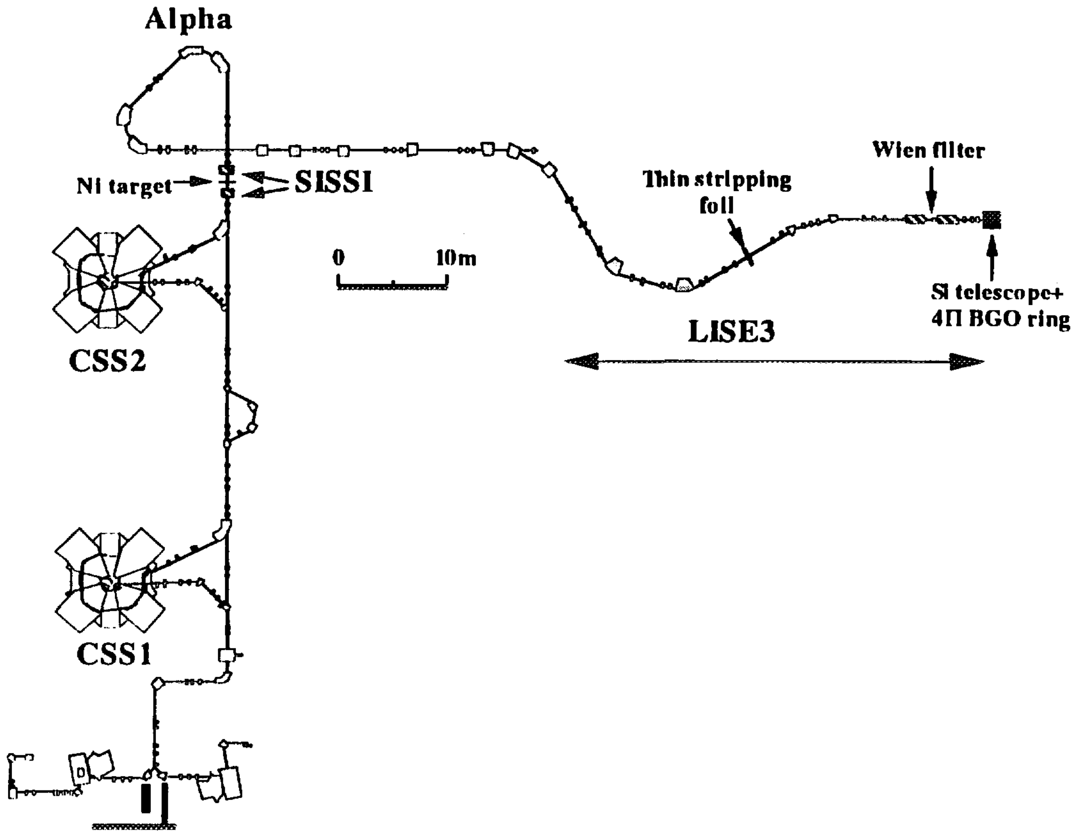
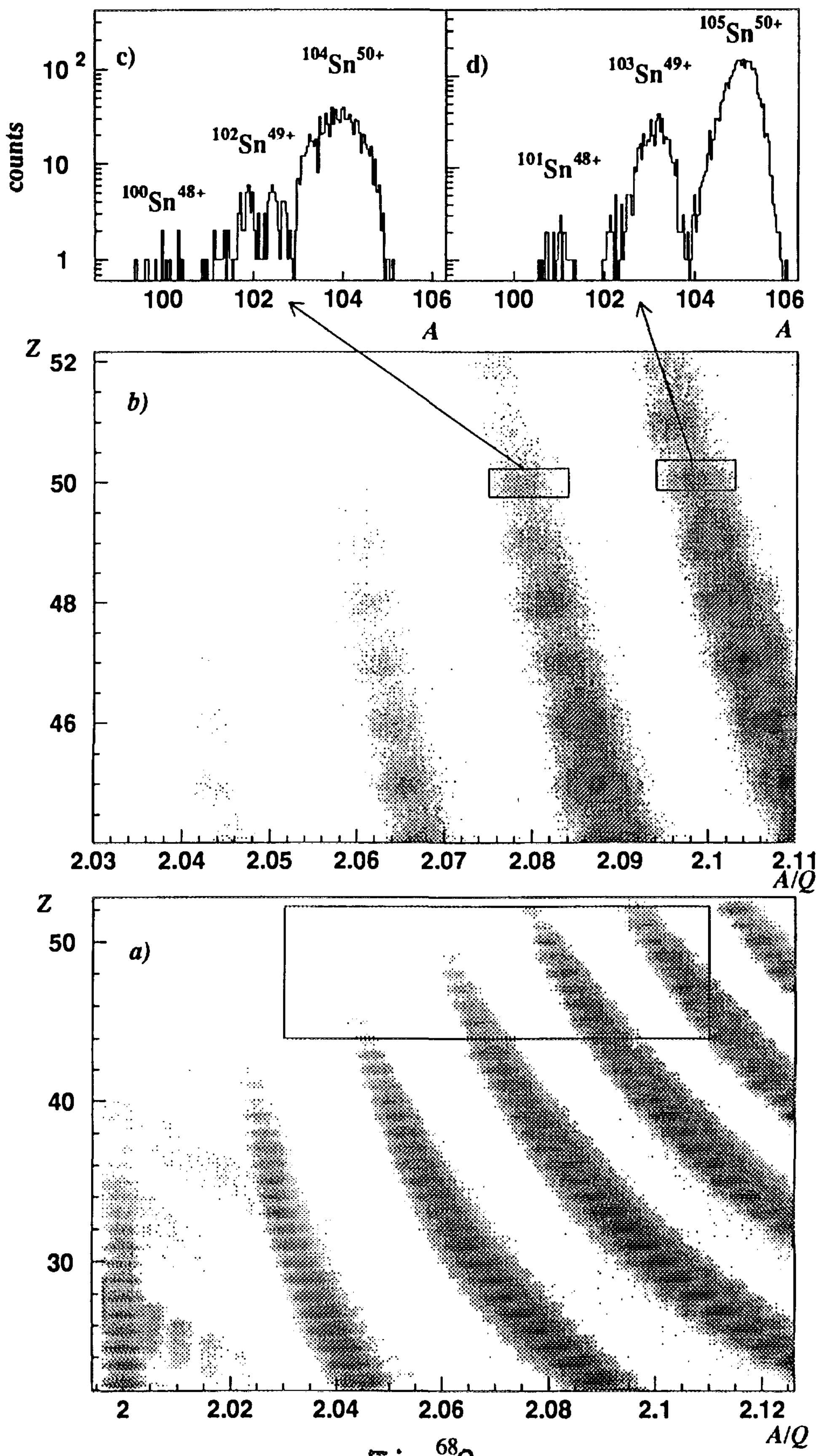

Alpha
Ni target
SISS1
CSS2
CSS1
0
10m
Thin stripping
foil
Wien filter
Si telescope+
4Π BGO ring
LISE3

Fig. 1



counts
c)
d)
$^{100}Sn^{48+}$
$^{102}Sn^{49+}$
$^{104}Sn^{50+}$
$^{101}Sn^{48+}$
$^{103}Sn^{49+}$
$^{105}Sn^{50+}$
A
b)
a)
Z
A/Q

Fig. 2

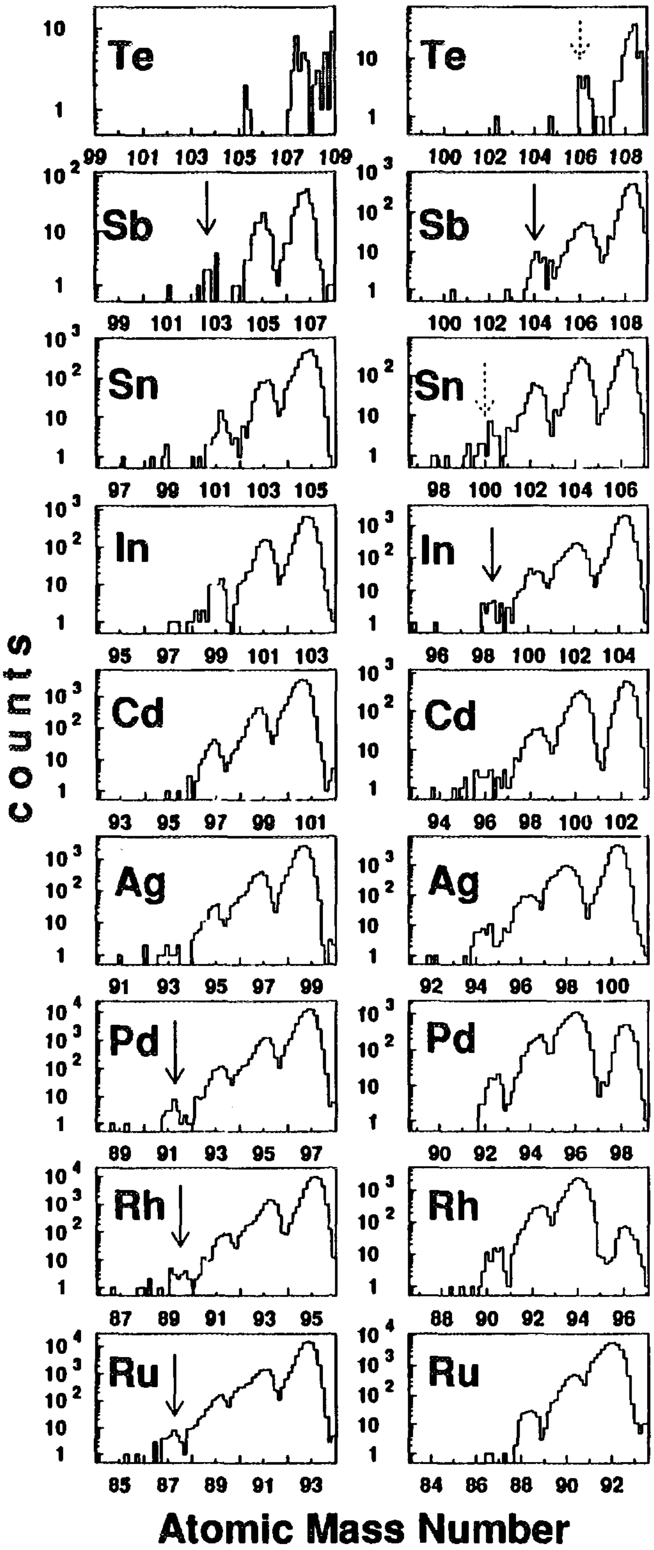

Te
Te
Sb
Sb
Sn
Sn
In
In
Cd
Cd
Ag
Ag
Pd
Pd
Rh
Rh
Ru
Ru
counts
Atomic Mass Number

Fig. 3