Forbidden and Gamow–Teller decay of N = 82 and N = 126 closed neutron shell nuclei

W. B. Walters, K. Kratz

Allowed and forbidden beta decay and neutron separation energies in r-process nucleosynthesis

William B. Walters and Karl-Ludwig Kratz

1. New results for Sn-135 and Sn-136
2. Effects of forbidden decay
3. Possible evidence for diffuse nuclear potential
4. r-process abundances in the 100 to 130 region
5. Shell effects and shell quenching
6. Neutron cloaking in the heavy Zr nuclides

Presented at Nuclear Structure 2000 held at Michigan State University, August 15-22, 2000 and to be published in Nuclear Physics A

Decay of ^{135,136}Sn isolated by use of a laser ion source and evidence for a more harmonic-oscillator-like nuclear potential

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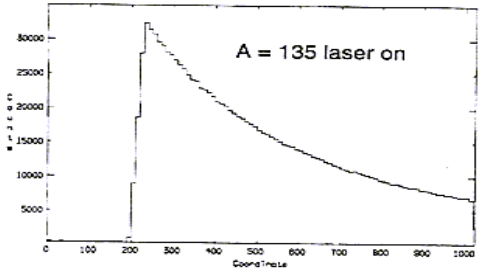
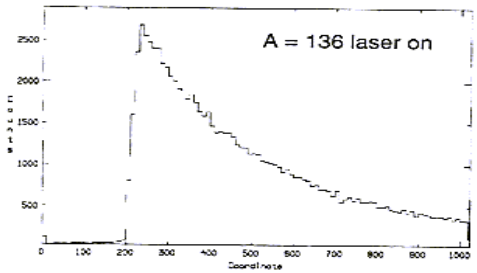
The use of a resonance ionization laser ion source at CERN/ISOLDE has made it possible to study the decay of very neutron-rich $^{135\text{-}137}$Sn. The decay of ^{135}Sn is found to populate low-energy levels in ^{135}Sb via direct beta decay and the first excited state in ^{134}Sb by beta-delayed neutron emission. The level structure of ^{135}Sb will be discussed and a possible signature for a more diffuse nuclear surface considered.



delay 600 ms
gate open 100 ms
274 pulses
127000 counts

1392 n/pulse



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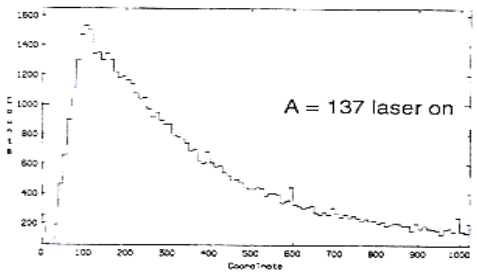
gate open 100 ms
404 pulses
87000 counts

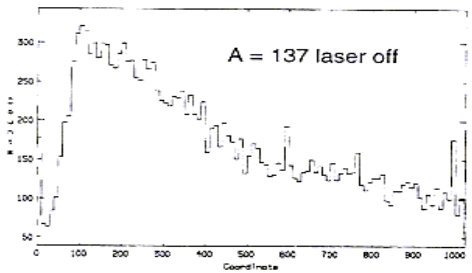
215 n/pulse



delay 100 ms
gate open 200 ms
881 pulses
55000 counts

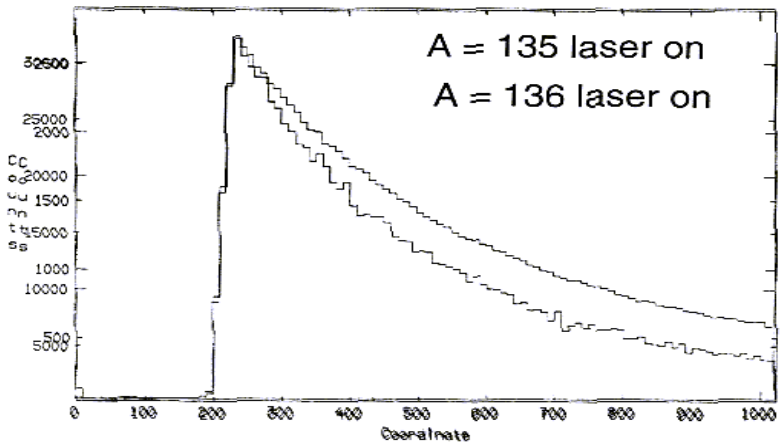
62 n/pulse

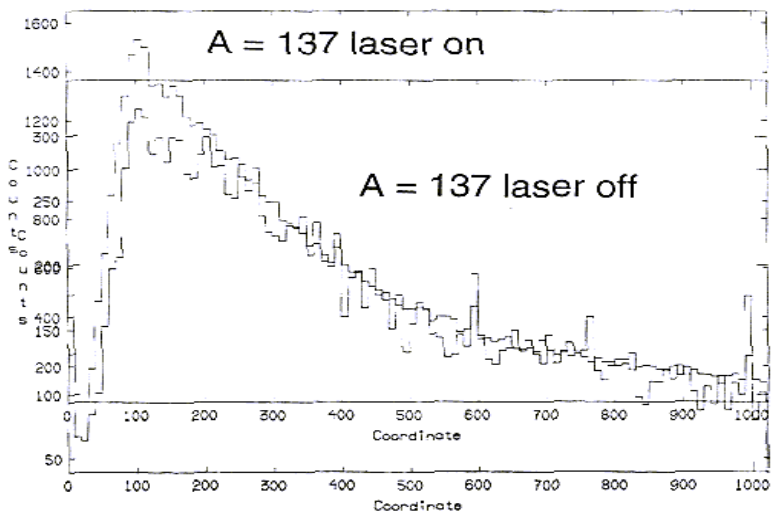
net = 31 n/pulse



delay 100 ms
gate open 200 ms
579 pulses
18000 counts

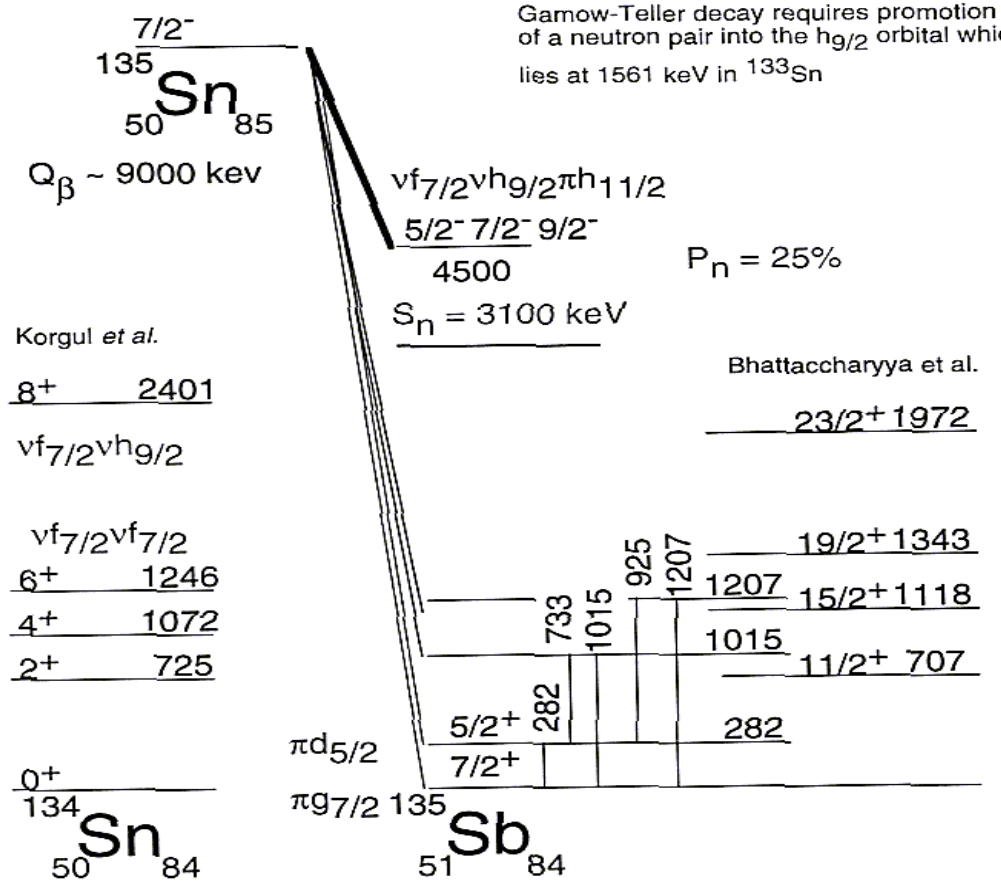
31 n/pulse


A = 135 laser on
A = 136 laser on
Coordinate


A = 137 laser on
A = 137 laser off
Coordinate
Coordinate

$t_{1/2}$ ~ 450(50) ms $\nu f_{7/2}(\nu h_{9/2}\nu h_{9/2}) \rightarrow \nu f_{7/2}\nu h_{9/2}\pi h_{11/2}$

Gamow-Teller decay requires promotion of a neutron pair into the $h_{9/2}$ orbital which lies at 1561 keV in ^{133}Sn



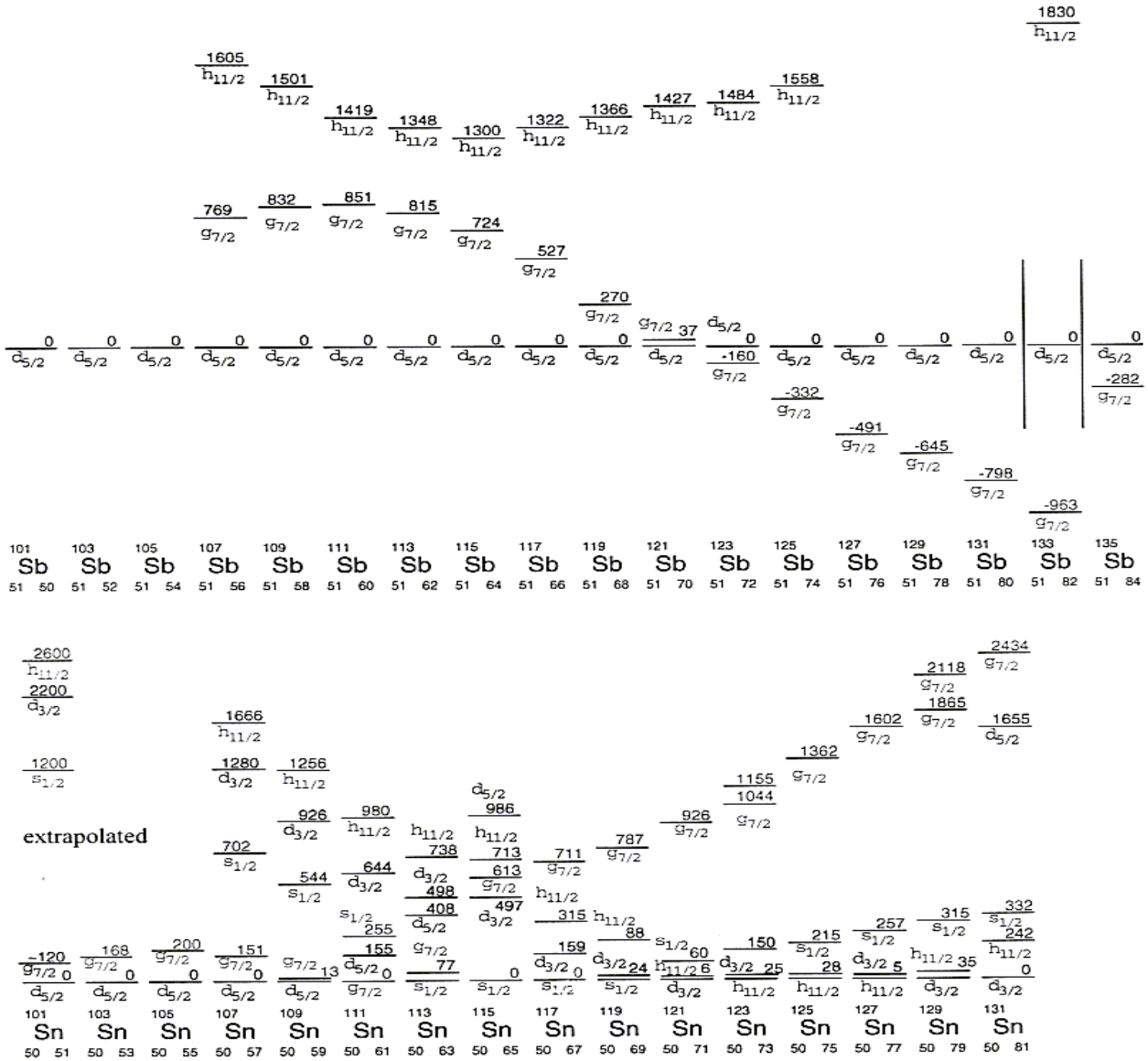
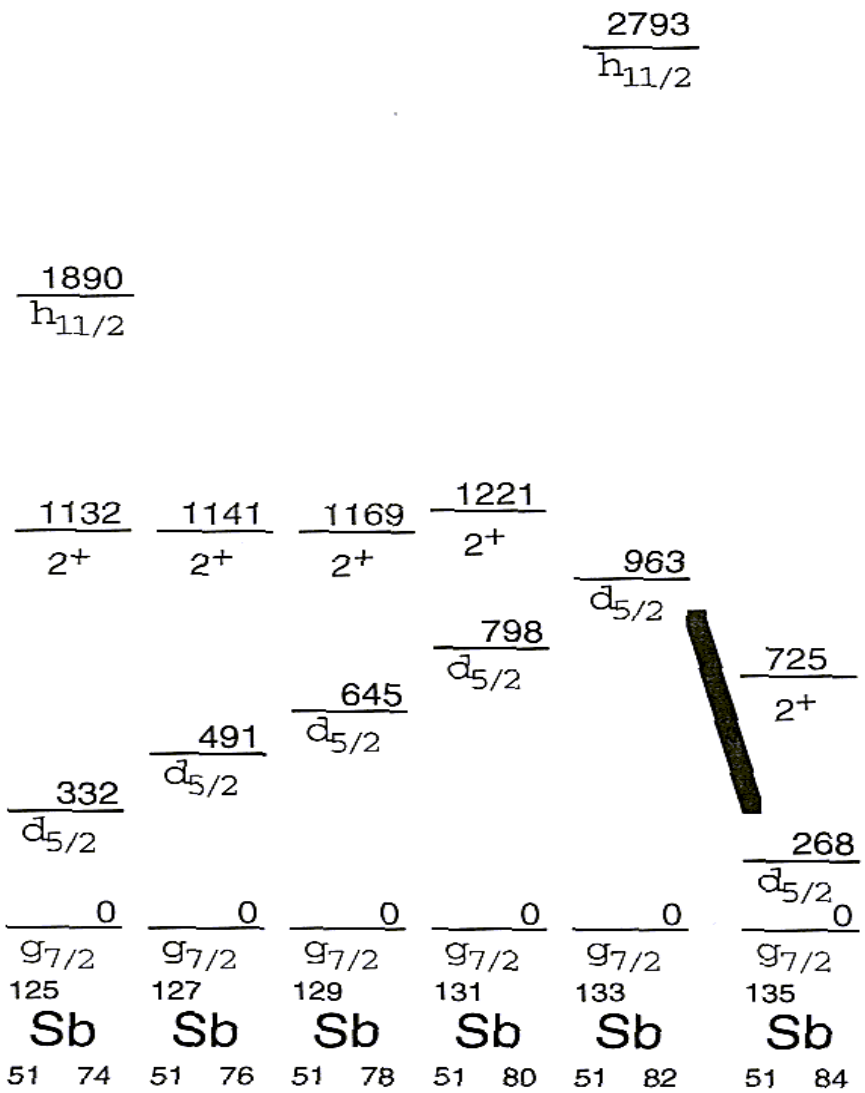
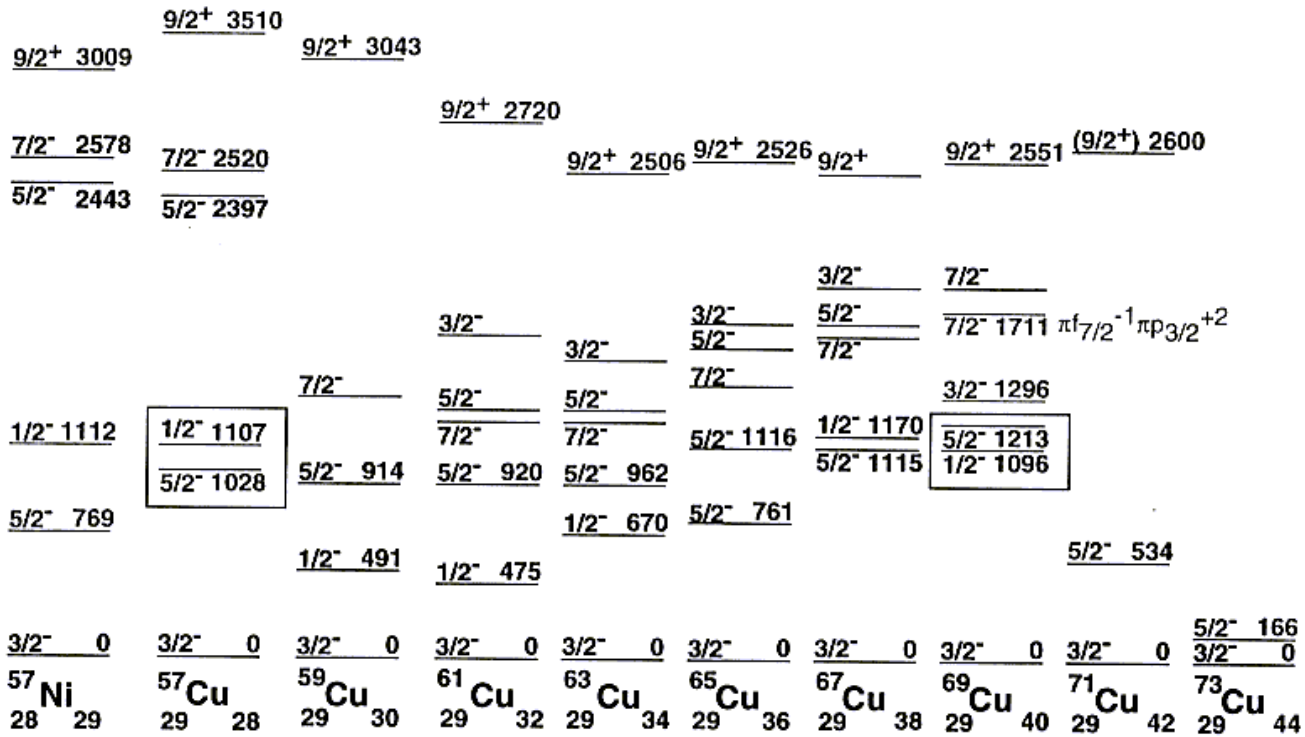
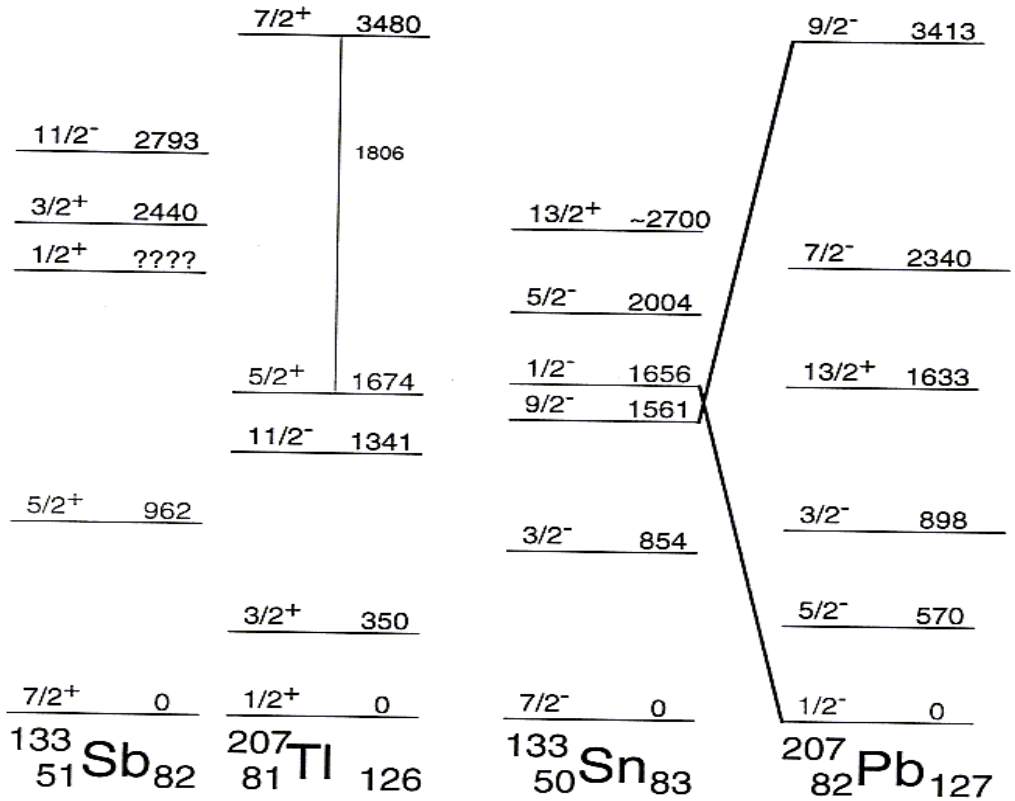


Figure 11. Monopole shifts of single-particle levels in the Sn and Sb nuclides.

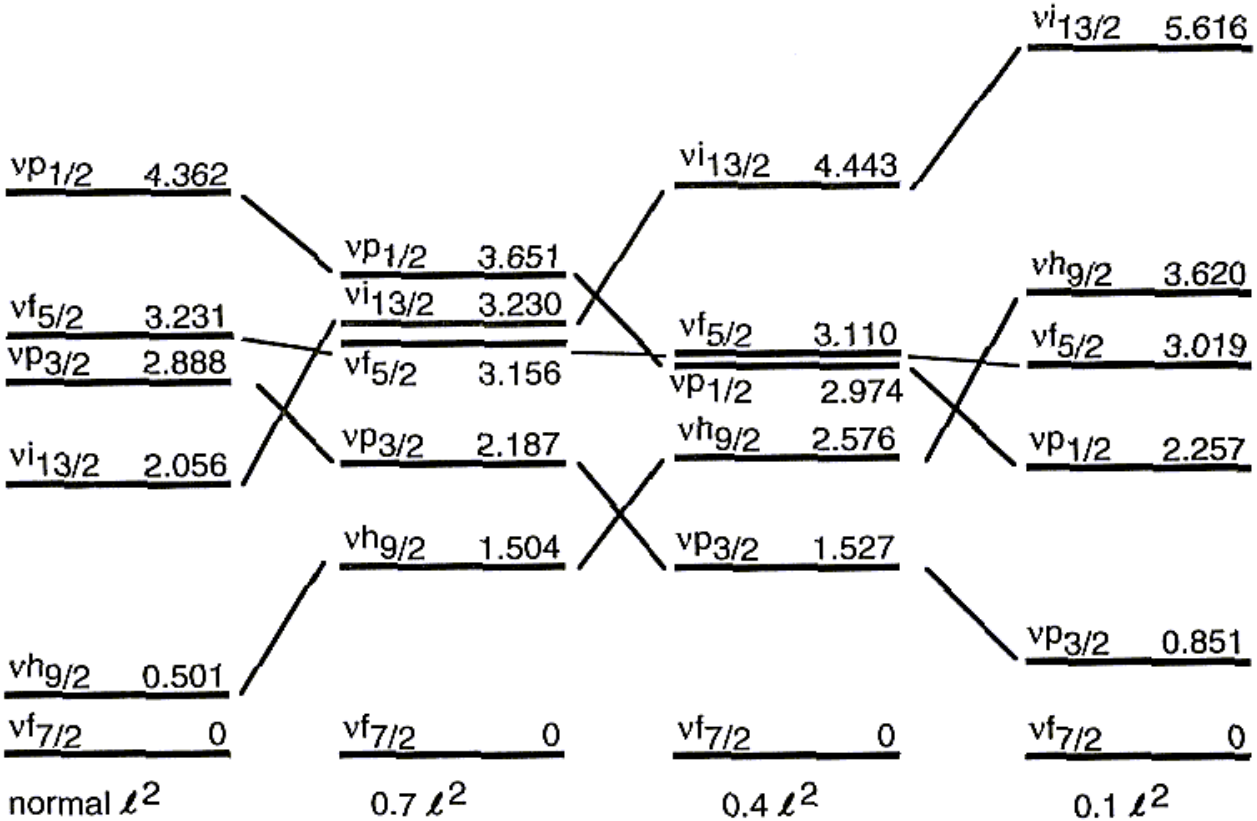

2793
h11/2
1890
h11/2
1132
2+
1141
2+
1169
2+
1221
2+
963
d5/2
798
d5/2
725
2+
645
d5/2
491
d5/2
332
d5/2
268
d5/2
0
g7/2
0
g7/2
0
g7/2
0
g7/2
0
g7/2
0
g7/2
125 Sb 51 74
127 Sb 51 76
129 Sb 51 78
131 Sb 51 80
133 Sb 51 82
135 Sb 51 84



Levels in odd-mass Cu nuclides.

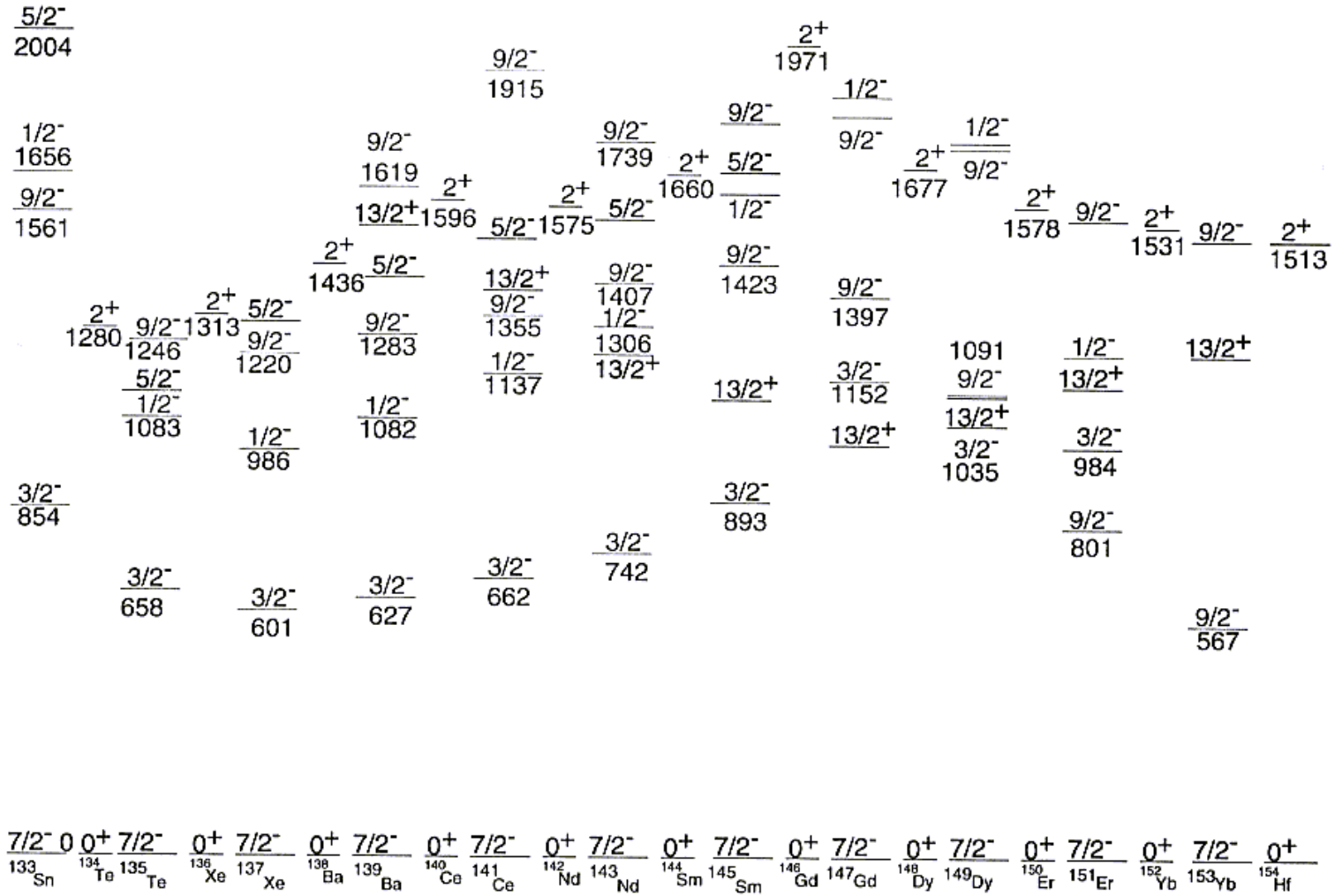


Sn-Pb Monopole shifts



Nilsson Neutron Potentials, $^{133}Sn_{83}$

N =83 ISOTONES



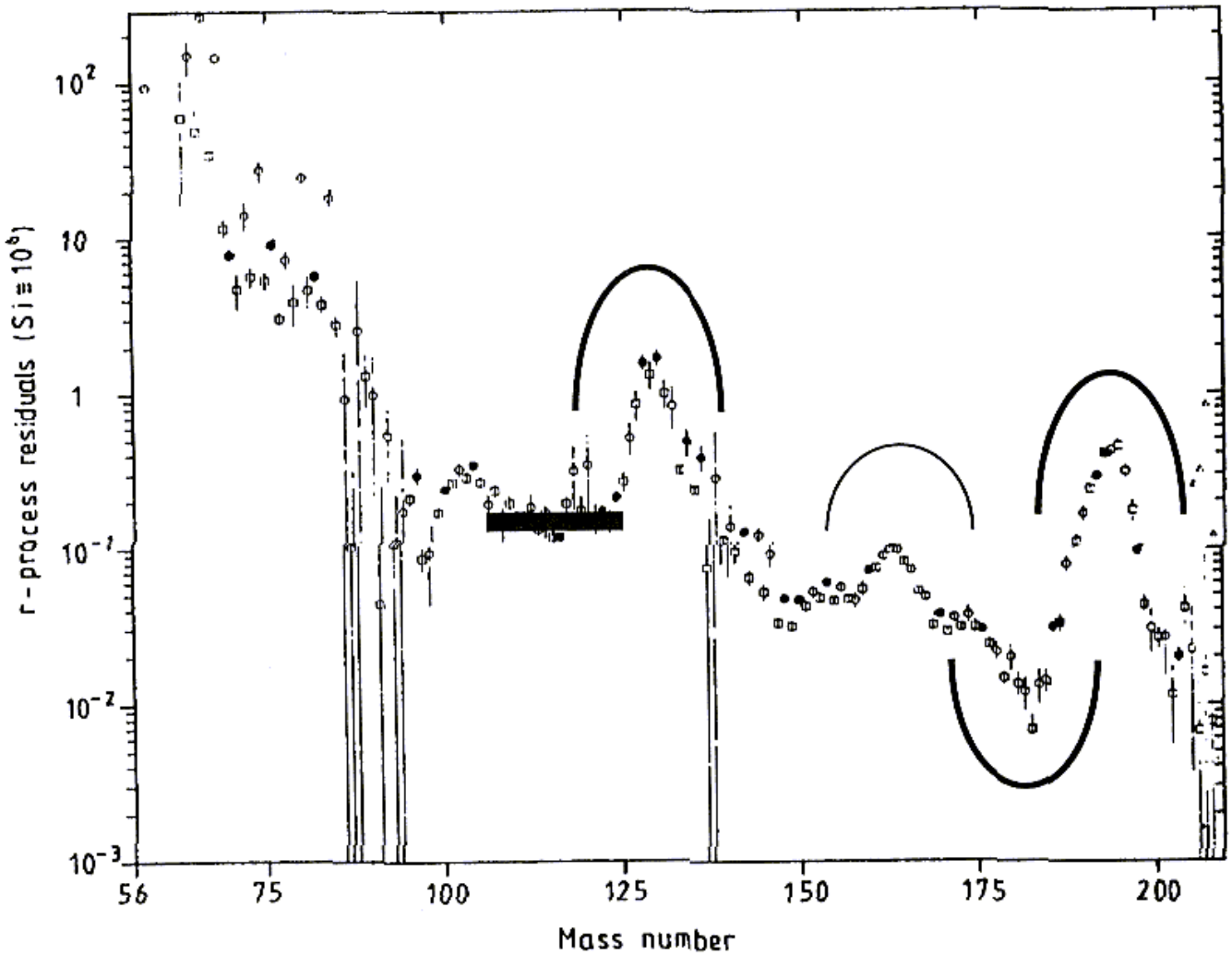
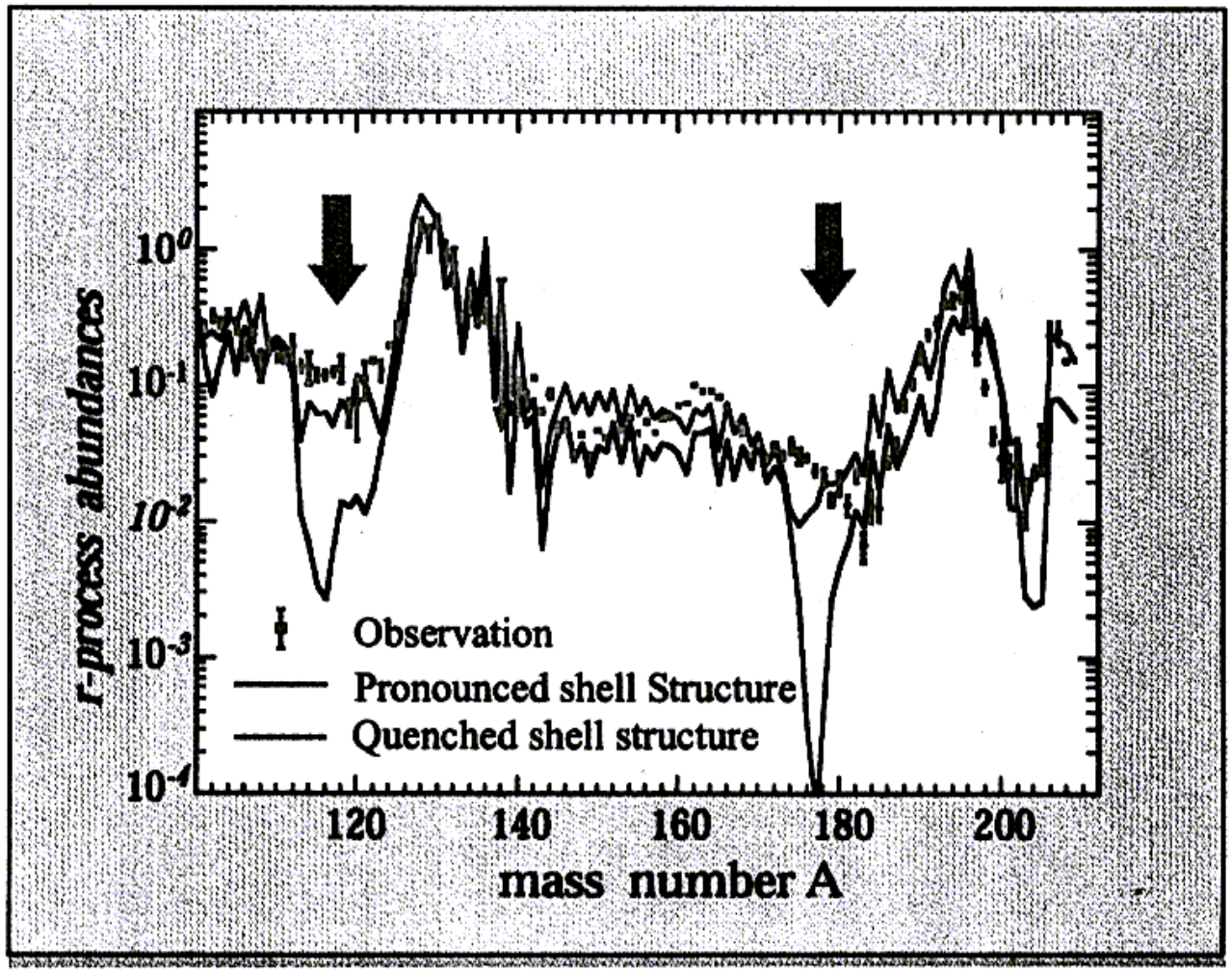
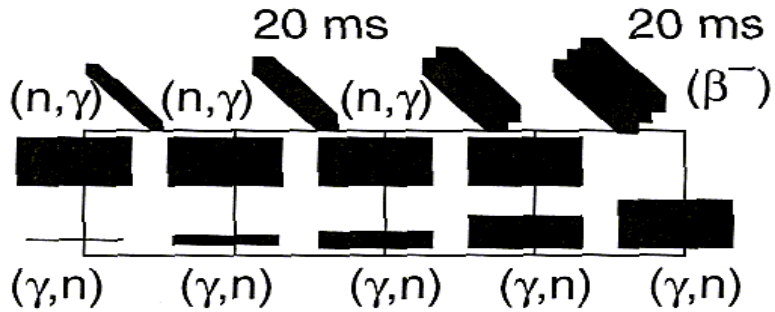


Figure 20. r-Process yields: the distribution of r-only isotopes (full points) and the abundances obtained by subtraction of s-process abundances from solar values (open symbols).


r-process abundances
10^0
10^-1
10^-2
10^-3
10^-4
120
140
160
180
200
mass number A
Observation
Pronounced shell Structure
Quenched shell structure

For a 5-second r-process, >200 neutrons must be captured and > 60 beta decays must occur.

5000 ms/(200 n + 60 β) < 20 ms/step



Half-lives ABOVE 25 ms FAVOR more neutron capture **if possible**, half-lives BELOW 20 ms favor decay.

The γ,n reaction will become important at the point where the neutron binding energy drops below the 2 MeV region and slows and stops the net forward neutron capture process.

BBFH - Kratz Waiting-point concept

includes the notion of a (n,γ) - (γ,n) equilibrium

neutron capture increases N, photodisintegration decreases N and beta decay increases Z

Equilibrium $\lambda N = C = N/t_{1/2}$

$\lambda_{net} = \Lambda_{for} - \Lambda_{bac}$

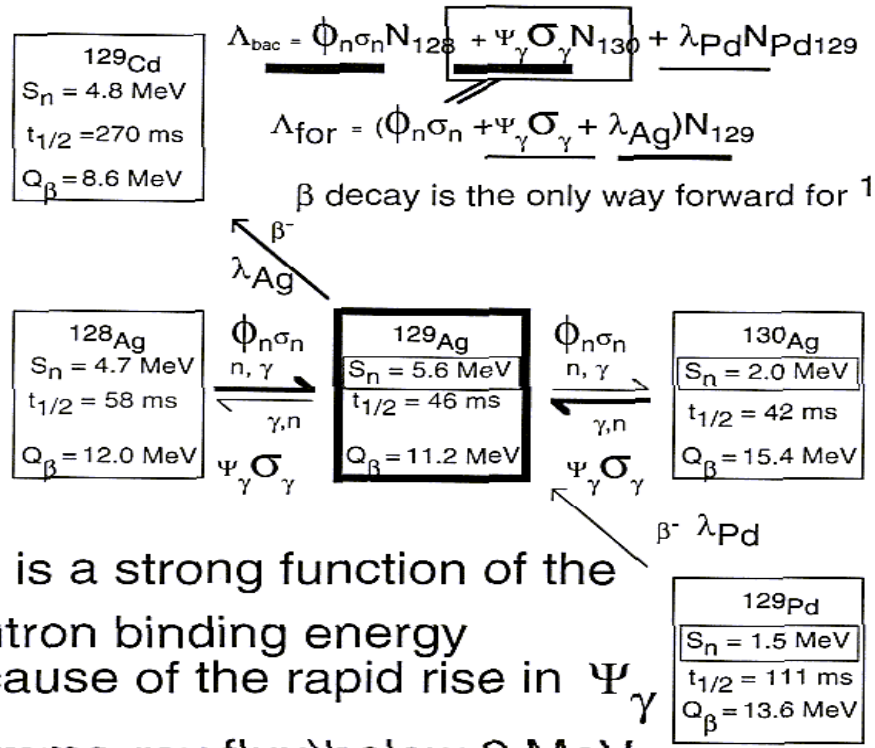
large N requires long $t_{1/2}$ (small λ_{net})

small N requires short $t_{1/2}$ (large λ_{net})

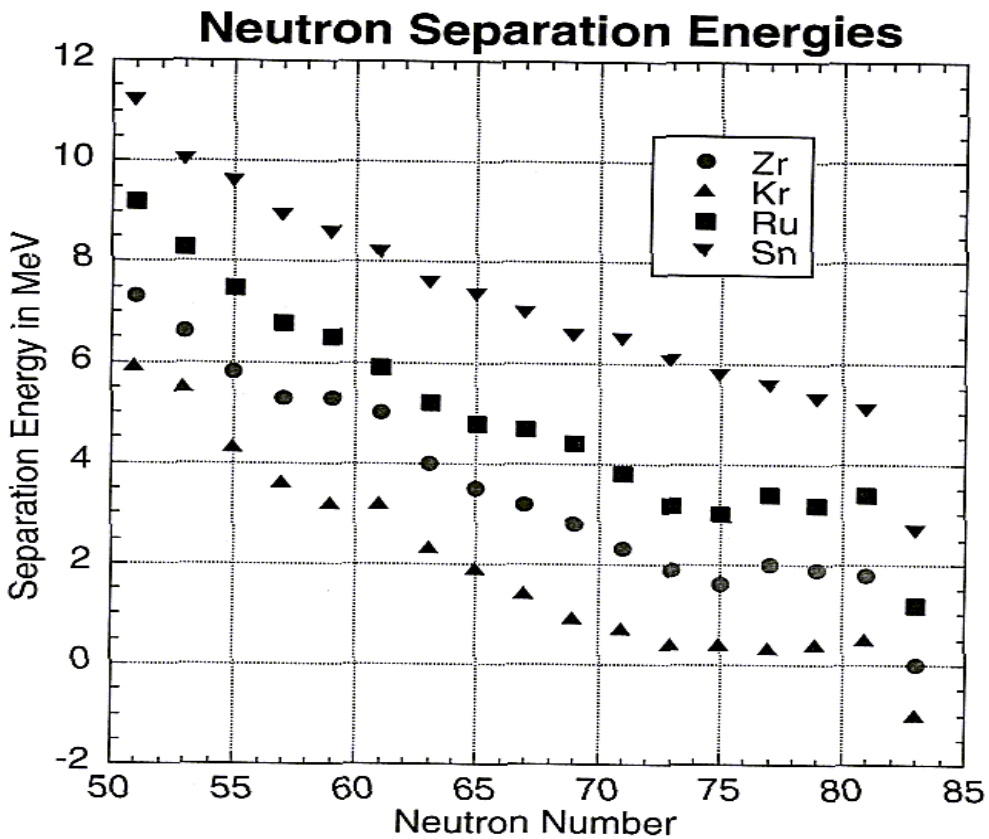
$$\Lambda_{bac} = \phi_n\sigma_n N_{128} + \Psi_\gamma\sigma_\gamma N_{130} + \lambda_{Pd} N_{Pd129}$$

$$\Lambda_{for} = (\phi_n\sigma_n + \Psi_\gamma\sigma_\gamma + \lambda_{Ag})N_{129}$$

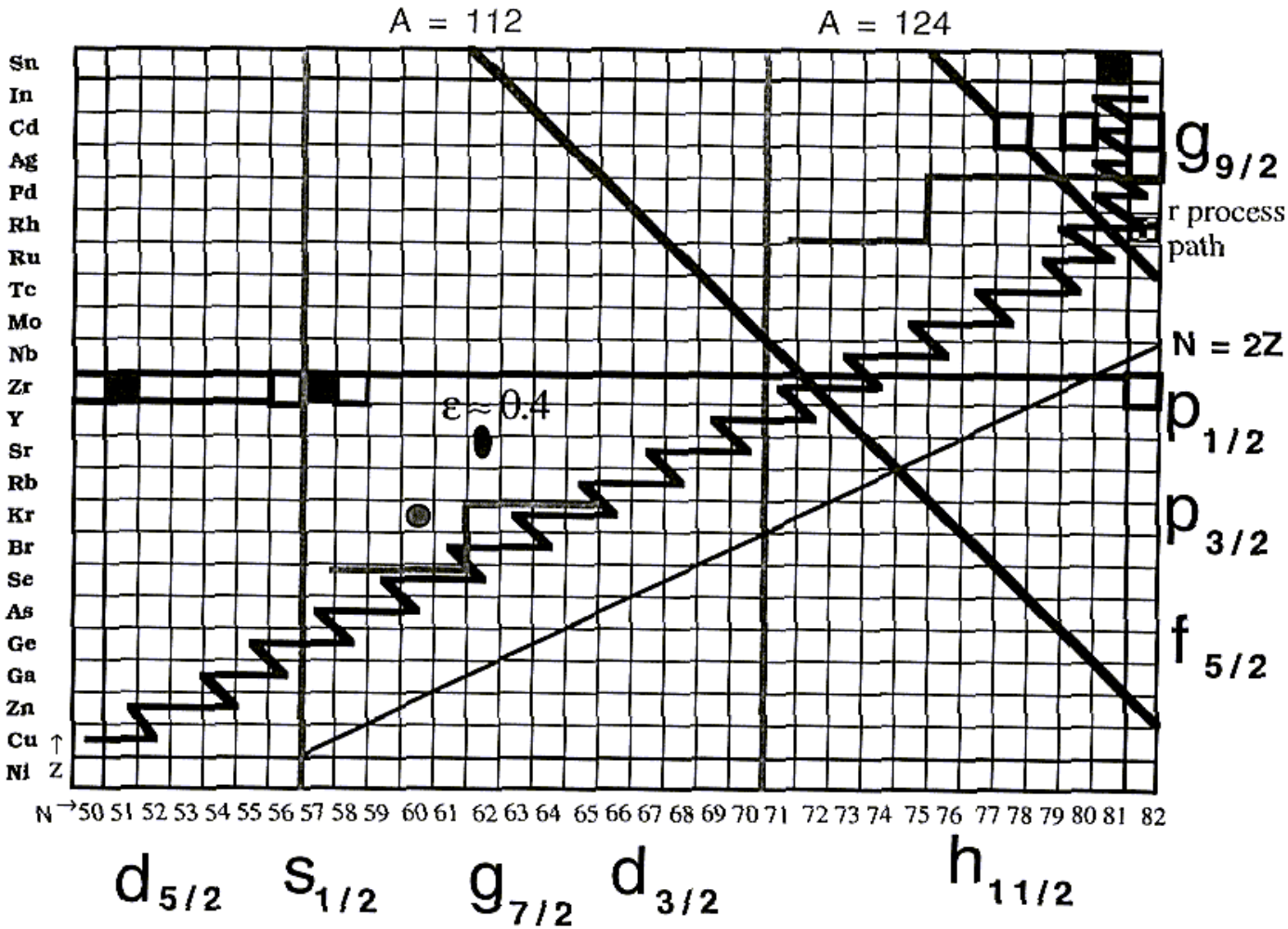
β decay is the only way forward for ^{129}Ag



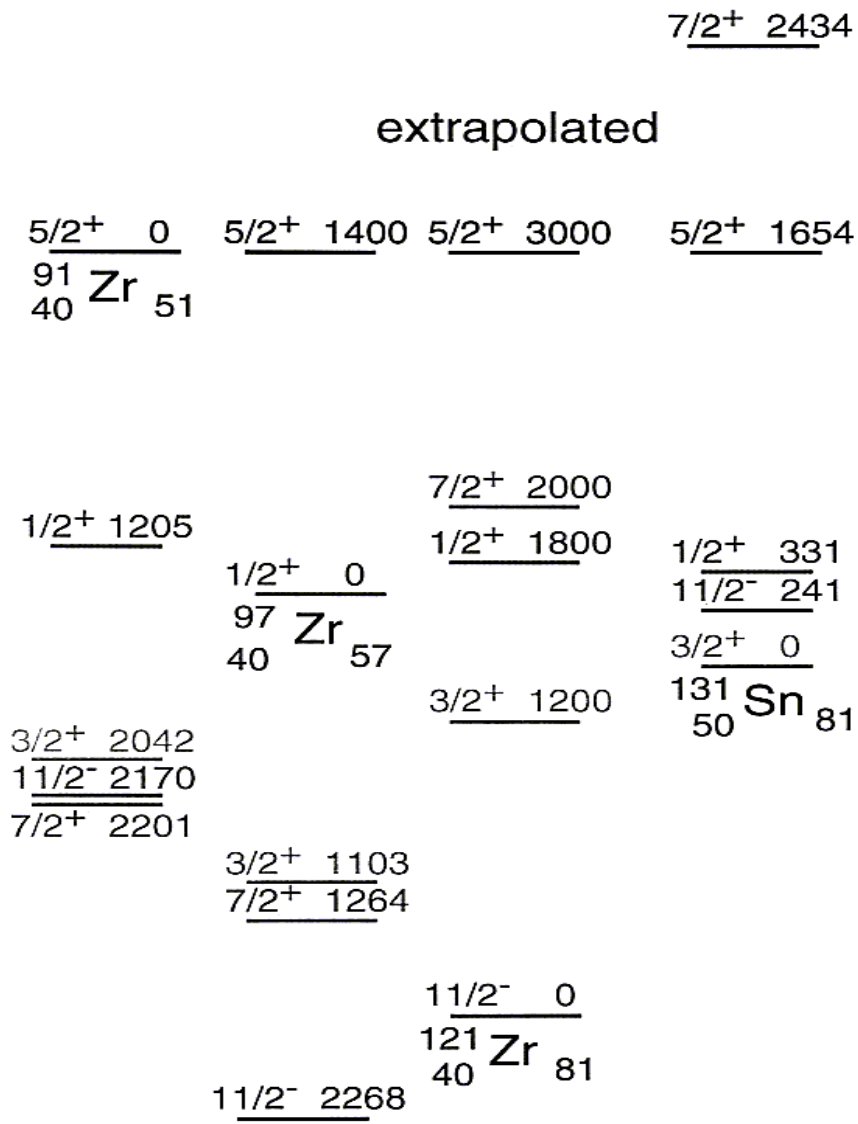
Λ_{bac} is a strong function of the neutron binding energy because of the rapid rise in Ψ_γ (gamma-ray flux)below 2 MeV.



From Möller, Nix and Kratz, ANDT **66**, 131 (1997).



schematic r-process path from ^{78}Ni to ^{132}Sn



Neutron monopole shifts from Zr-90 to Sn-132

N=5

large Circular orbital

5/2+ 3000

FANCY

CLOAK

7/2+ 2434

7/2+ 2201

11/2- 2268

11/2- 2170

N=3 protons

7/2+ 2000

3/2+ 2042

1/2+ 1800

5/2+ 1654

5/2+ 1400

1/2+ 1205

7/2+ 1264

3/2+ 1200

3/2+ 1103

fact

fact

fact

1/2+ 331

11/2- 241

5/2+ 0

1/2+ 0

11/2- 0

3/2+ 0

$^{91}_{40}Zr_{51}$

$^{97}_{40}Zr_{57}$

$^{121}_{40}Zr_{81}$

$^{131}_{50}Sn_{81}$

Possible monopole shifts for neutrons in the N = 50 to N = 82 region for Zr nuclides.

Summary:

New data for Sn-135 and Sn-136 decay show a significant contribution for forbidden decay

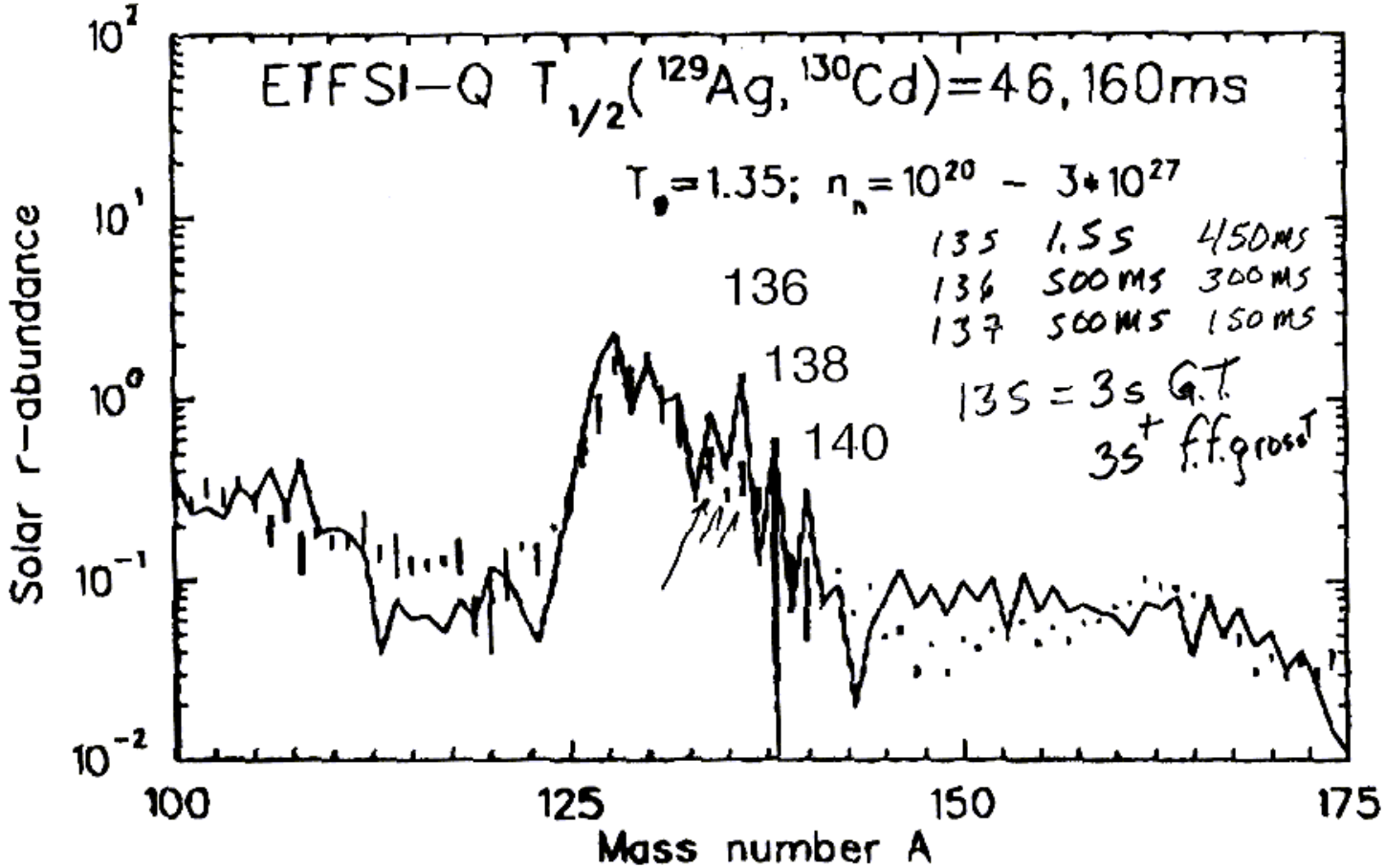
The new half lives will lower the discrepancy between observed and calculated values for these masses in the r-process abundances

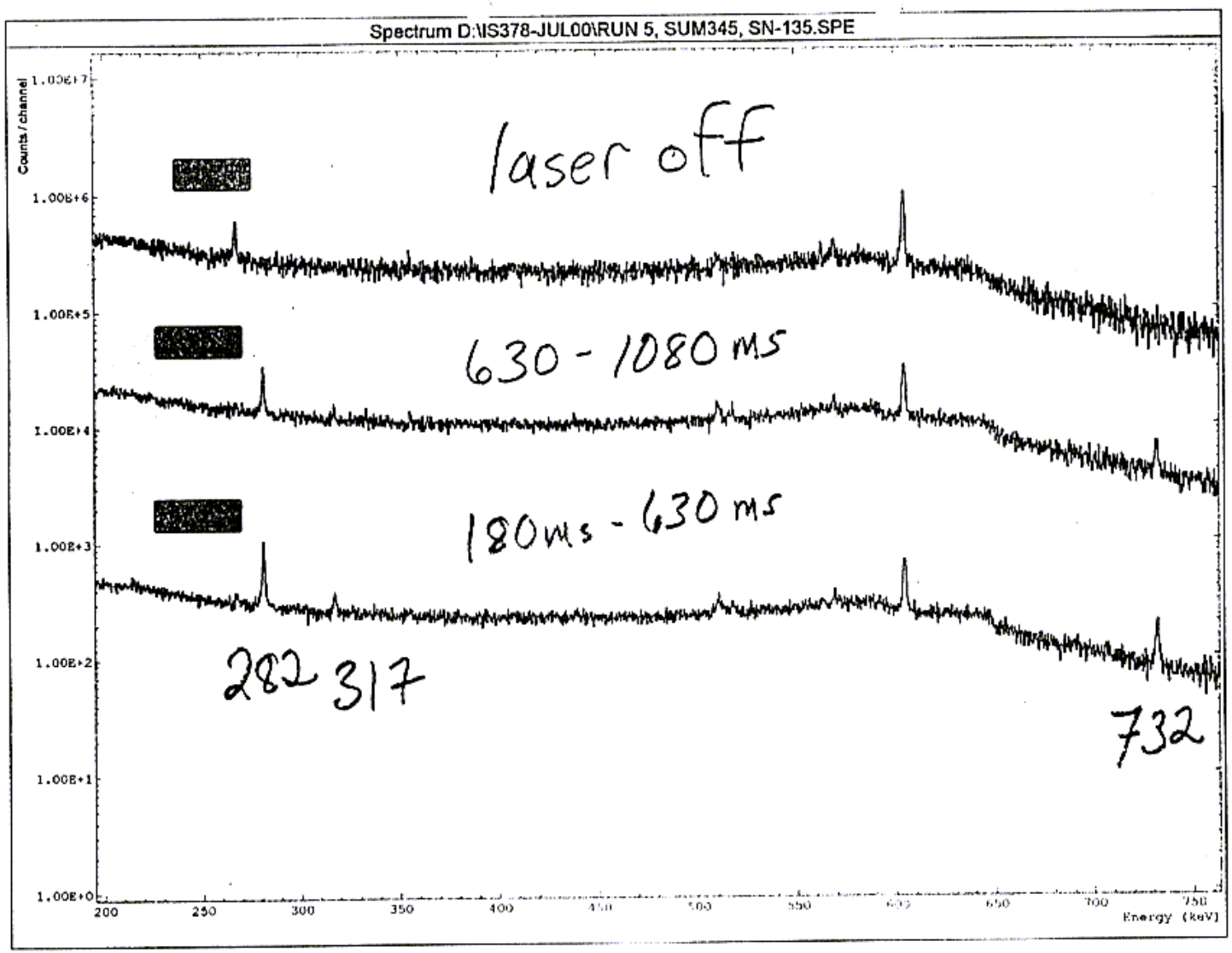
Low position for the $5/2^+$ state in Sb-135 may suggest a more harmonic-oscillator-like nuclear shape

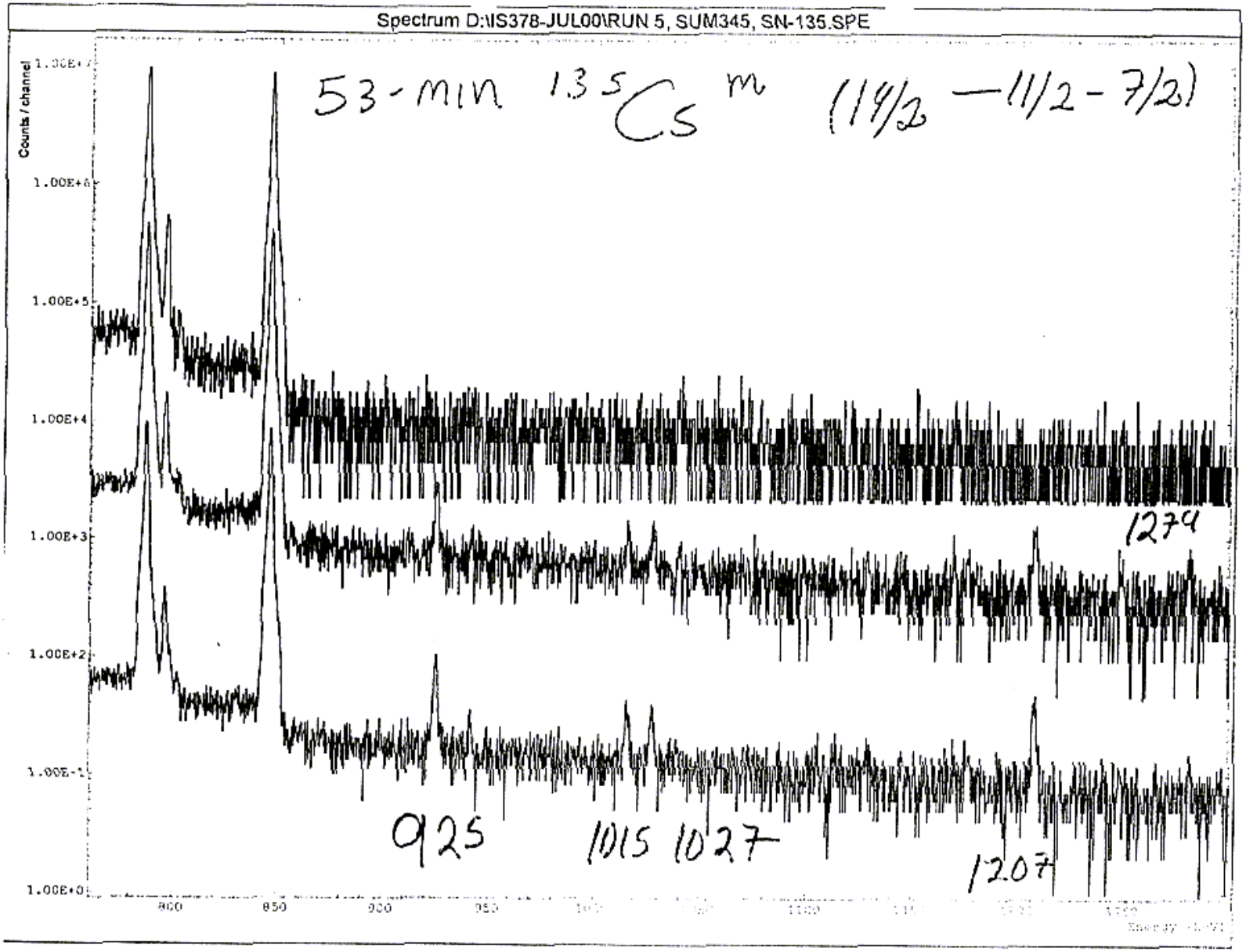
r-process abundances from A = 100 to 125 do not show calculated effects for N =82 closed shell

Possible skin of h-11/2 neutrons that are less strongly bound

A region (A = 95 – 125) much in need of new data


ETFSI–Q $T_{1/2}(^{129}Ag, ^{130}Cd)$=46, 160ms
T_9=1.35; $n_n = 10^{20} - 3*10^{27}$
135 1.5s 450ms
136 500ms 300ms
137 500ms 150ms
135 = 3s G.T.
$3s^+$ f.f.gross
136
138
140
Solar r–abundance
Mass number A
10^2
10^1
10^0
10^{-1}
10^{-2}
100
125
150
175


Spectrum D:\IS378-JUL00\RUN 5, SUM345, SN-135.SPE
Counts / channel
1.00E+7
1.00E+6
1.00E+5
1.00E+4
1.00E+3
1.00E+2
1.00E+1
1.00E+0
200
250
300
350
400
450
500
550
600
650
700
750
Energy (keV)
laser off
630 - 1080 ms
180ms - 630 ms
282
317
732


Spectrum D:\IS378-JUL00\RUN 5, SUM345, SN-135.SPE
Counts / channel
1.00E+6
1.00E+5
1.00E+4
1.00E+3
1.00E+2
1.00E+0
800
850
900
53-min 135 Cs m (14/2 — 11/2 - 7/2)
1274
925
1015 1027
1207

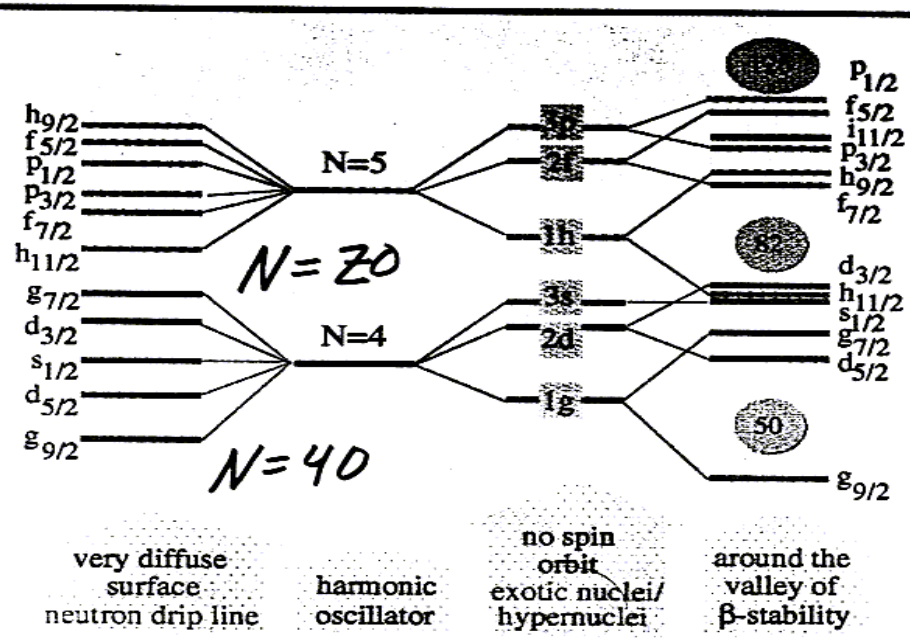
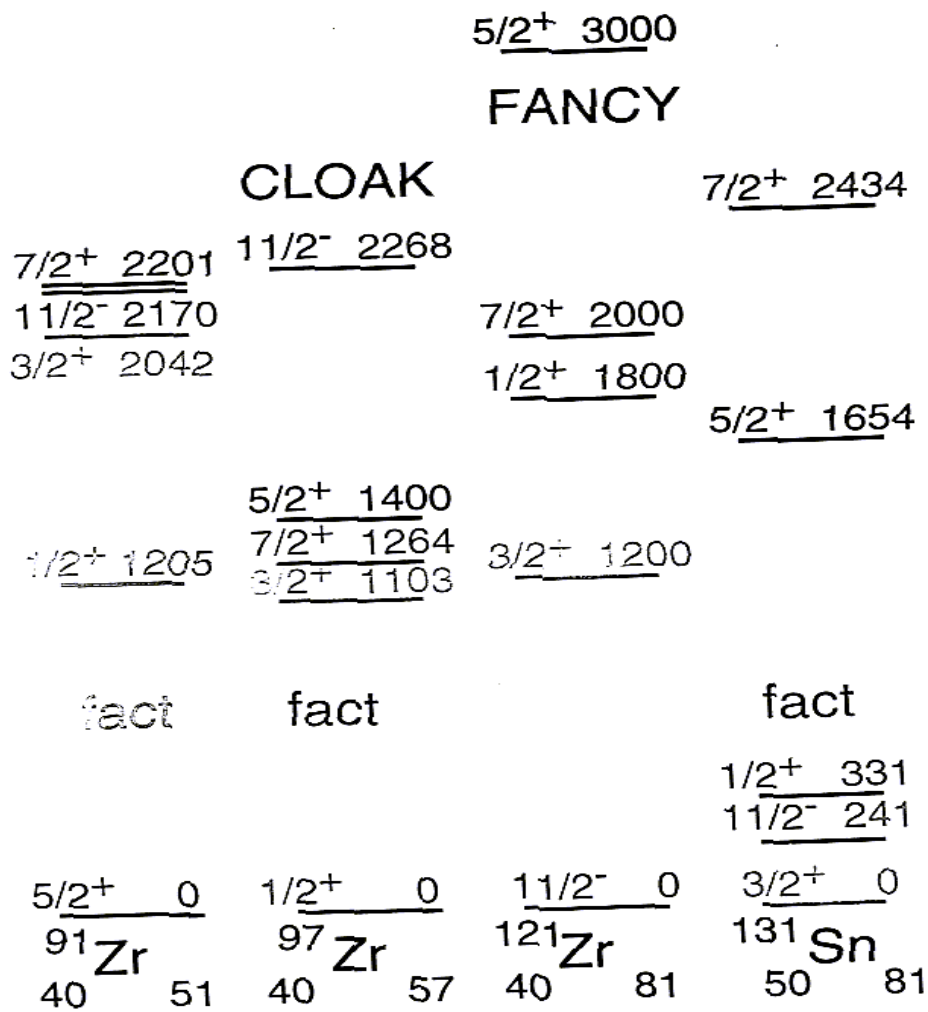


Figure 27: Single-particle spectrum for different nuclear potentials [dob96]. The shell structure characteristic of nuclei close to stability, shown in the column on the right, appears modified for neutron-rich nuclei due to the weak binding energy and the strong pairing force, as shown in the column on the left.



Possible monopole shifts for neutrons in the N = 50 to N = 82 region for Zr nuclides.