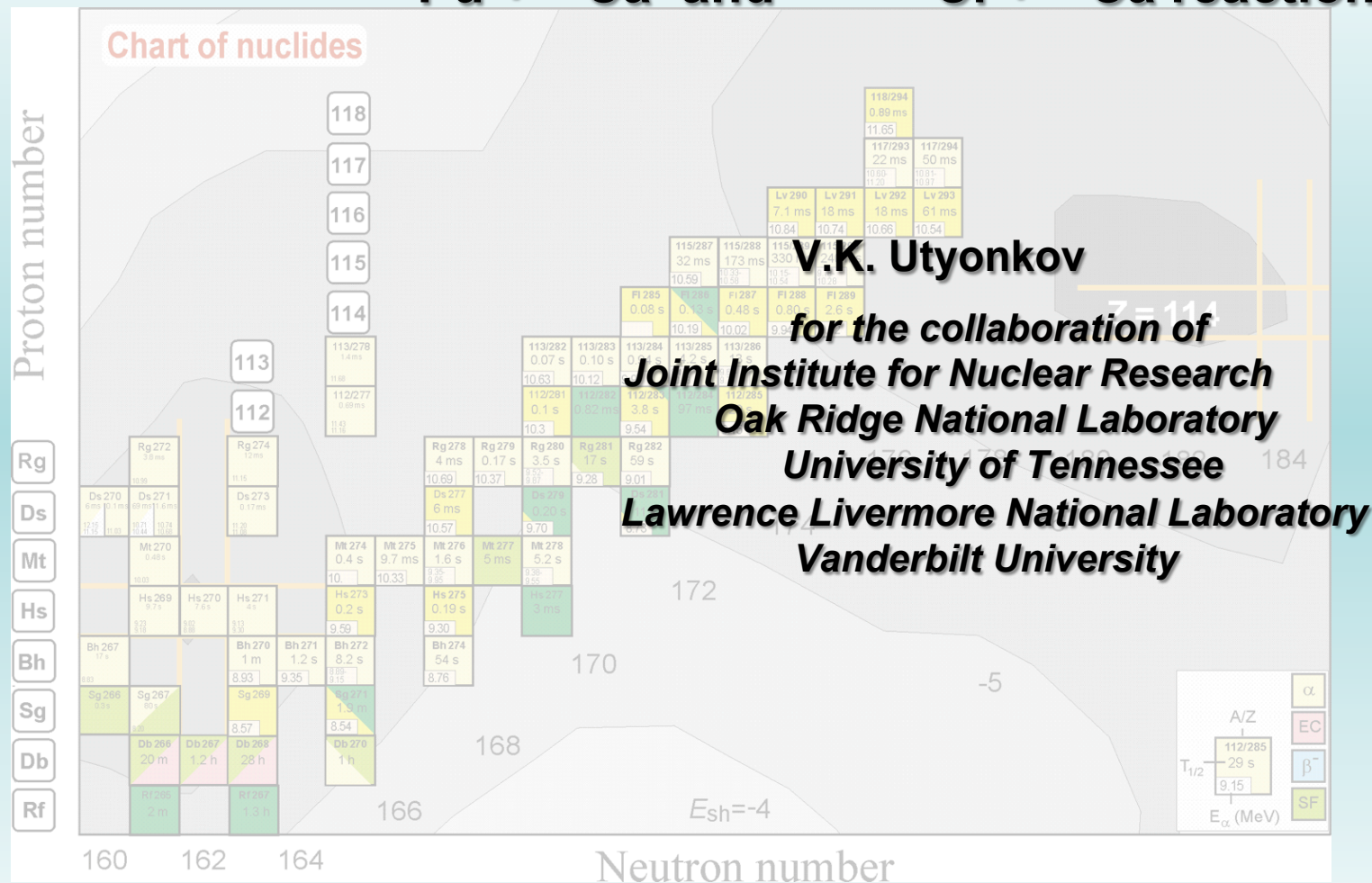
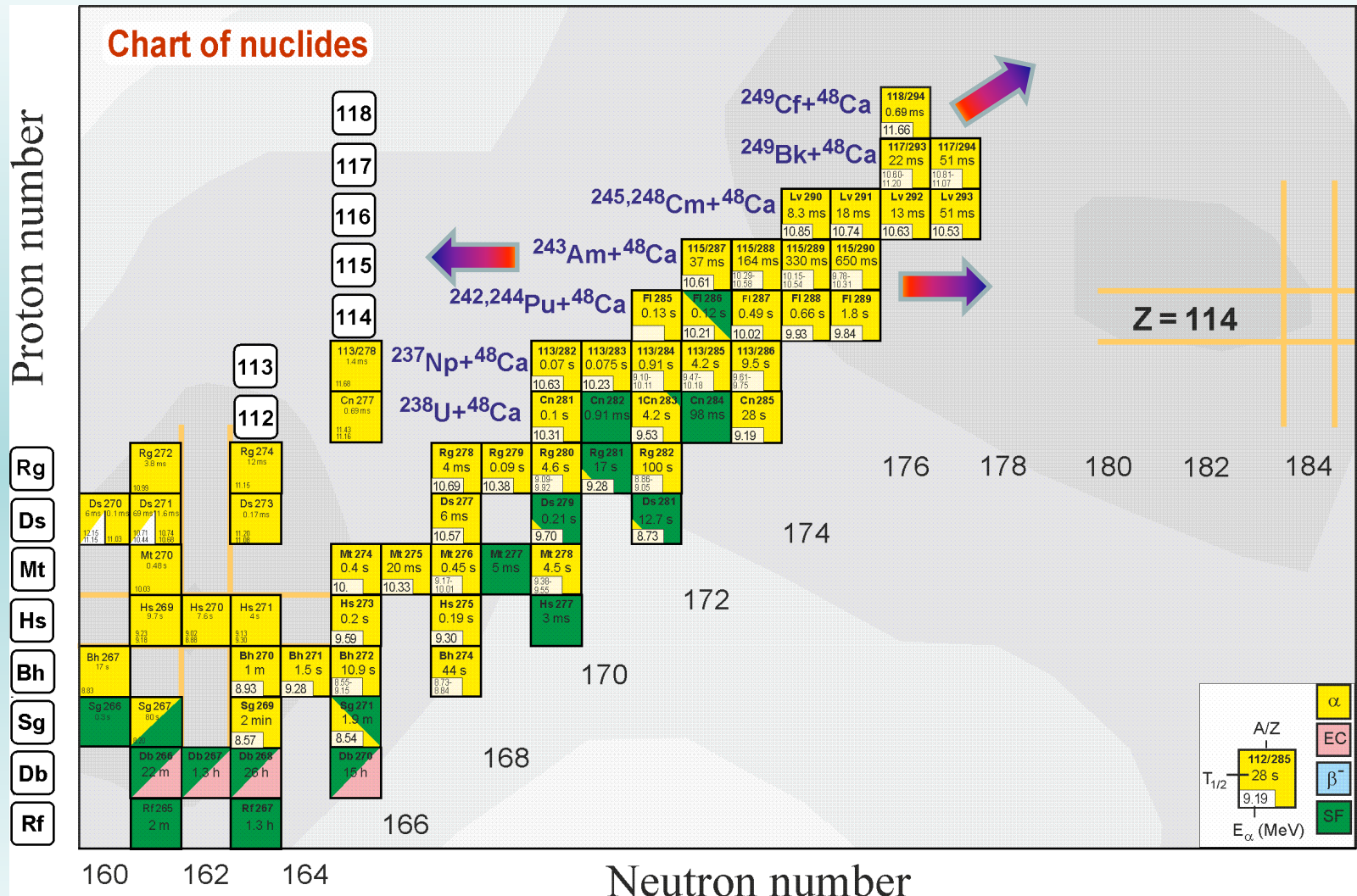


# Synthesis of superheavy nuclei at limits of stability: $^{239,240}\text{Pu} + ^{48}\text{Ca}$ and $^{249-251}\text{Cf} + ^{48}\text{Ca}$ reactions

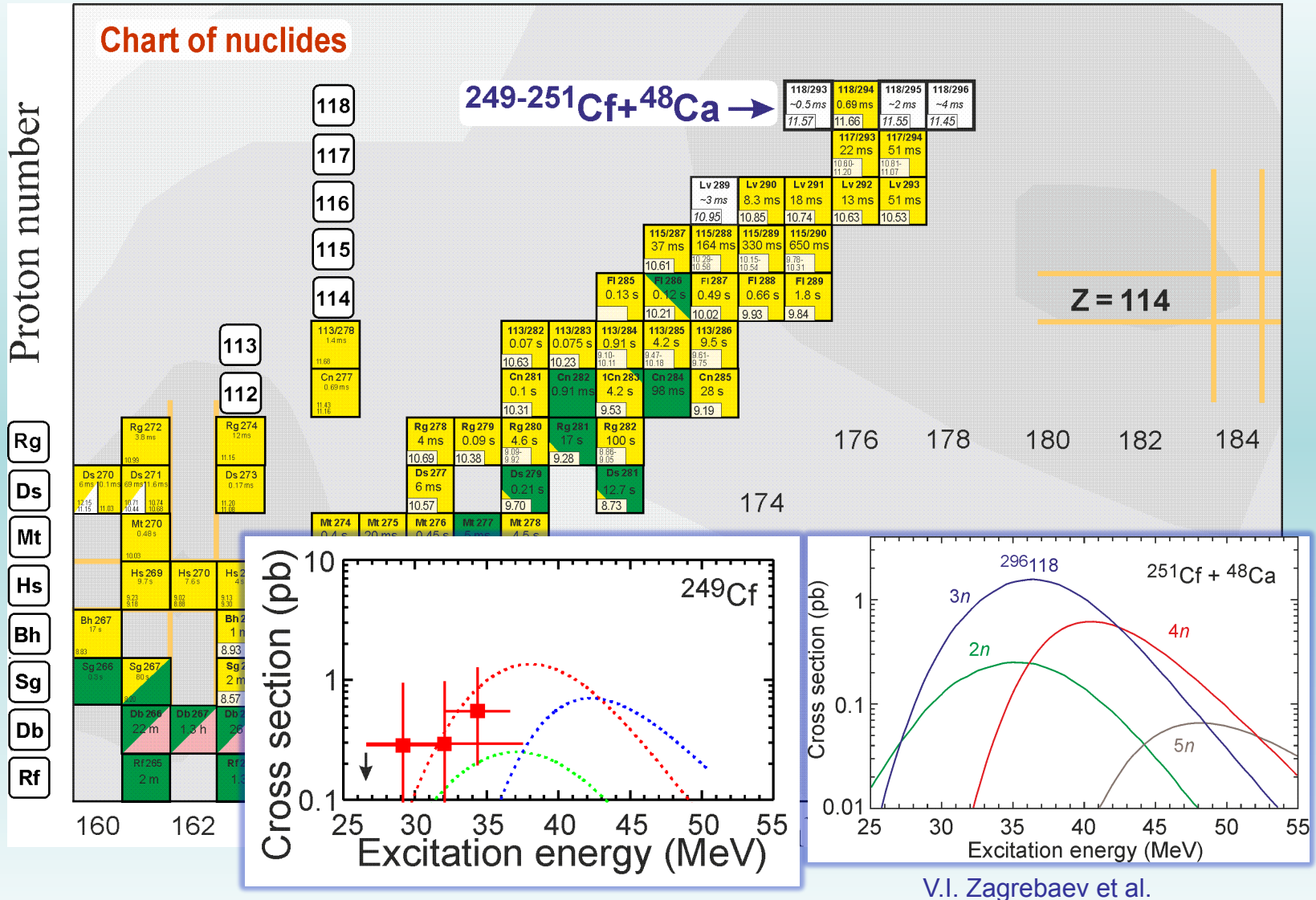


**Super Heavy Nuclei**  
**International Symposium**  
**Texas A & M University, College Station TX, USA**  
**March 31 - April 02, 2015**

# Region of superheavy nuclei



# Synthesis of the heaviest isotopes of element 118 in the $^{249-251}\text{Cf} + ^{48}\text{Ca}$ reaction





# Synthesis of the heavies isotopes of element 118 in the $^{249-251}\text{Cf} + ^{48}\text{Ca}$ reaction

$^{249}\text{Cf}$  (351 y)  
5.61 mg  
50.7%

$^{250}\text{Cf}$  (13 y)  
1.43 mg  
12.9%

$^{251}\text{Cf}$  (898 y)  
**4.03 mg**  
**36.4%**

$^{252}\text{Cf}$  (2.65 y)  
0.002 mg  
0.02%

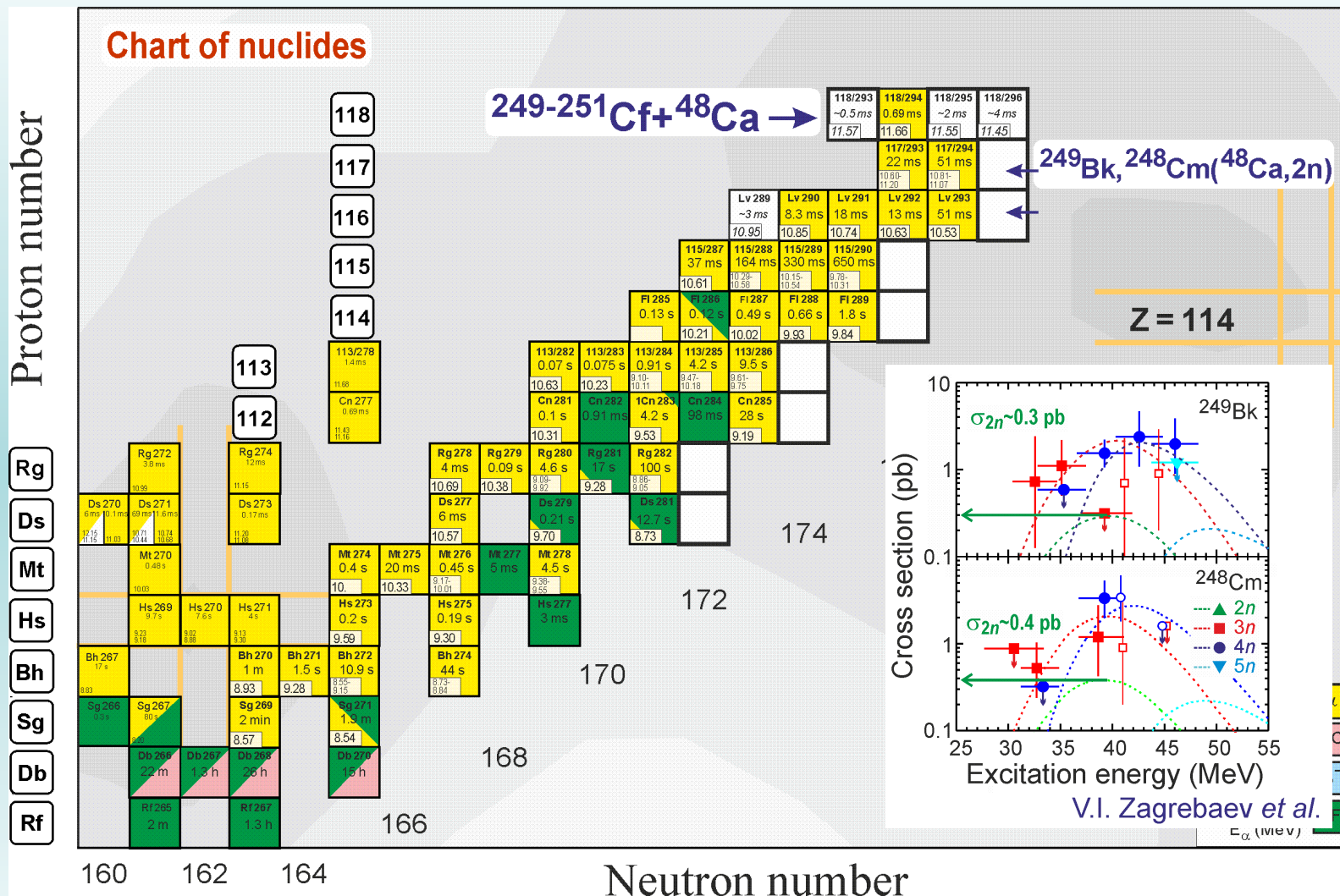


work on mixed Cf  
at REDC

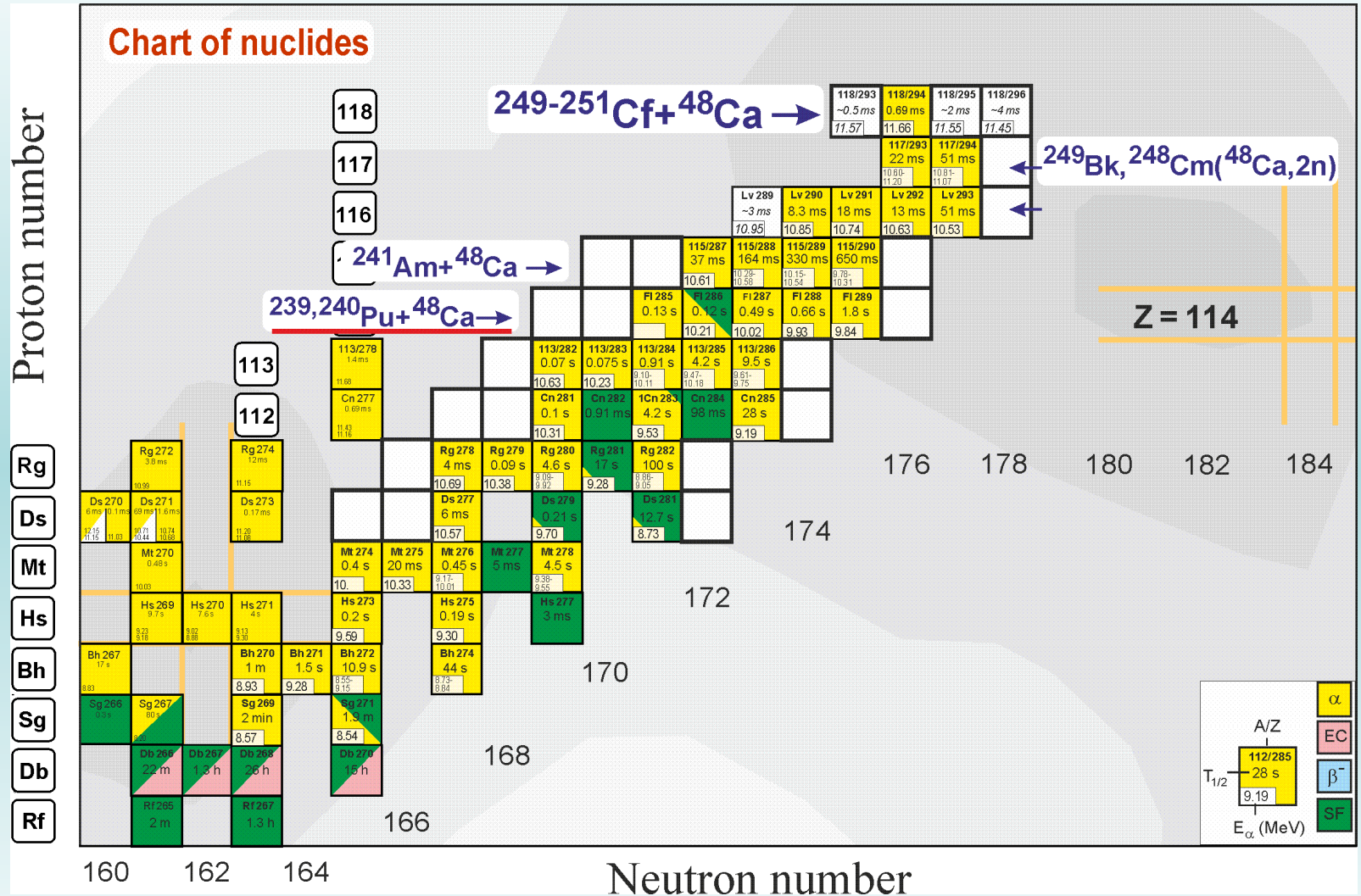


12 target sectors are in Dubna  
Average thickness 0.35 mg/cm<sup>2</sup>

## Synthesis of the heavies isotopes in the 2n-evaporation channel



# Synthesis of neutron-deficient isotopes



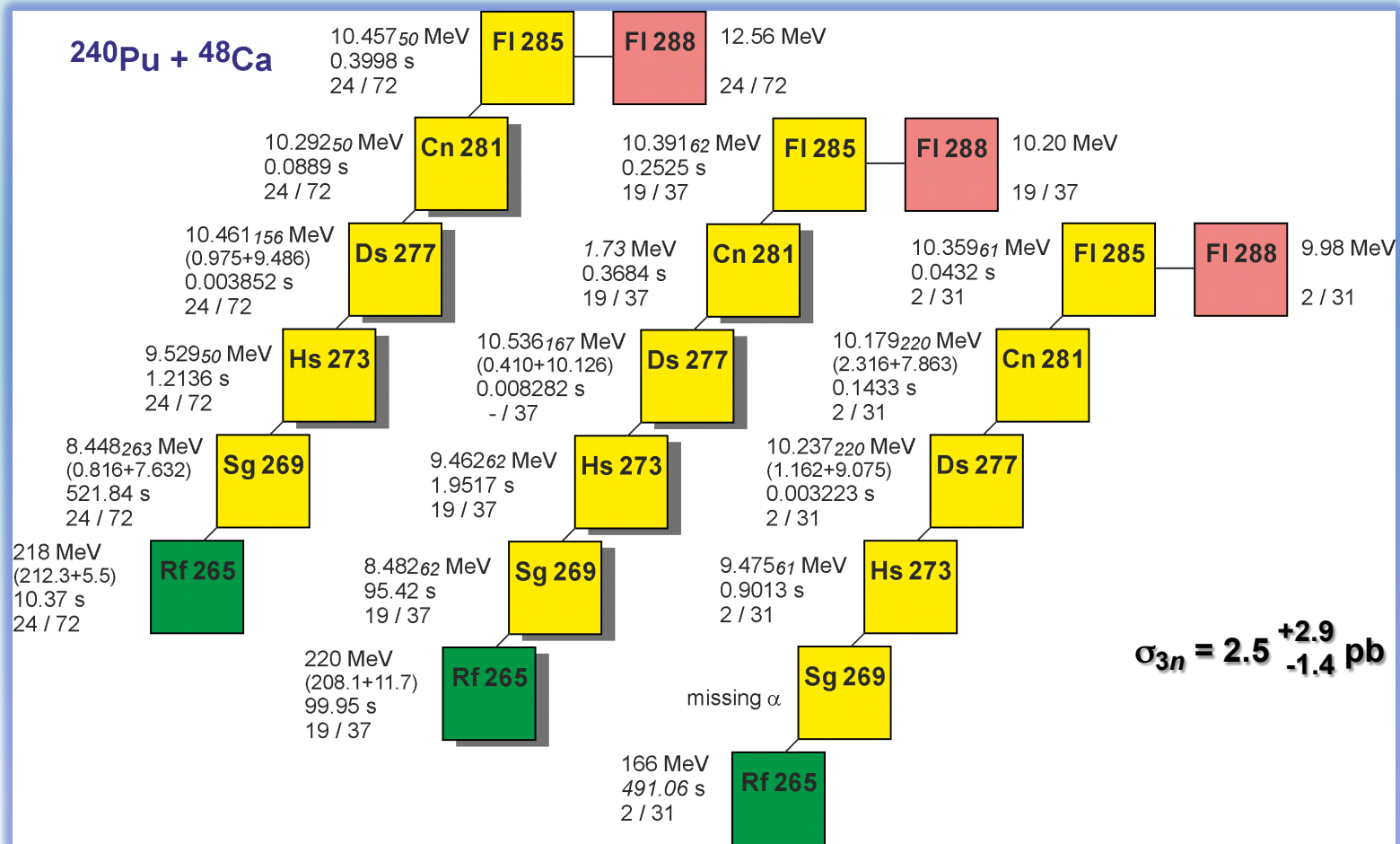


# Synthesis of neutron-deficient isotopes

$^{240}\text{Pu} + ^{48}\text{Ca}$  reaction

Target  
Energy of  $^{48}\text{Ca}$   
Excitation energy  
Beam dose

$0.49 \text{ mg/cm}^2$   
**245 MeV**  
**36.5 – 41.1 MeV**  
 **$4.0 \cdot 10^{18}$**



# Synthesis of neutron-deficient isotopes

## $^{240}\text{Pu} + ^{48}\text{Ca}$ reaction

**Target**  
**Energy of  $^{48}\text{Ca}$**   
**Excitation energy**  
**Beam dose**

**0.49 mg/cm<sup>2</sup>**  
**250 MeV**  
**40.9 – 45.4 MeV**  
 **$4.7 \times 10^{18}$**

### $^{240}\text{Pu} + ^{48}\text{Ca}$

168 MeV 0.555 ms 17 / 118	<b>FI 284</b>	<b>FI 288</b>	14.43 MeV 17 / 118	190 MeV (173+17) 0.857 ms 35 / 19,20	<b>FI 284</b>	<b>FI 288</b>	13.18 MeV 35 / 19,20
140 MeV 8.588 ms 15 / 59	<b>FI 284</b>	<b>FI 288</b>	10.24 MeV 15 / 59	234 MeV (179+55) 7.246 ms 27 / 46	<b>FI 284</b>	<b>FI 288</b>	10.66 MeV 27 / 46

$$\sigma_{4n} = 2.6^{+3.3}_{-1.7} \text{ pb}$$

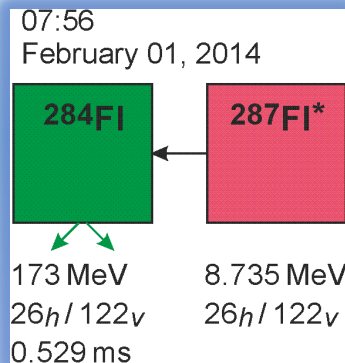
Events could originate from isomers with very low probabilities of  $4 \times 10^{-3}$  and  $2 \times 10^{-10}$ .  
 They were not observed at 245-MeV  $^{48}\text{Ca}$  energy: Agreement with expectations for the  $4n$ -reaction channel.  
 Agreement with calculated and measured decay properties of even-even nuclei.



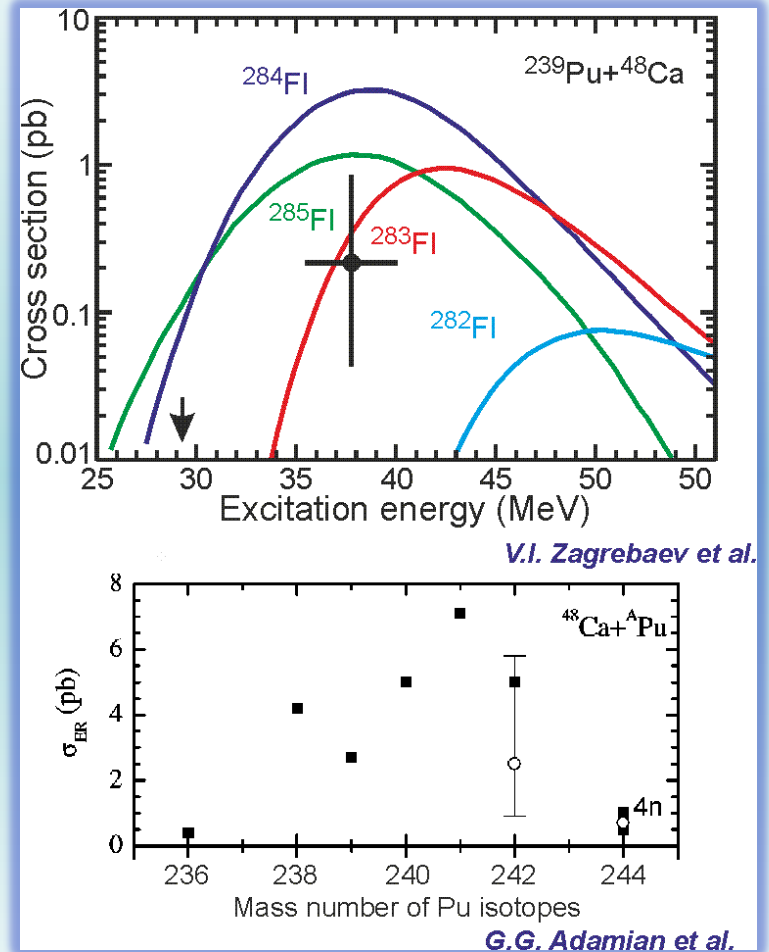
# Synthesis of neutron-deficient isotopes

## $^{239}\text{Pu} + ^{48}\text{Ca}$ reaction

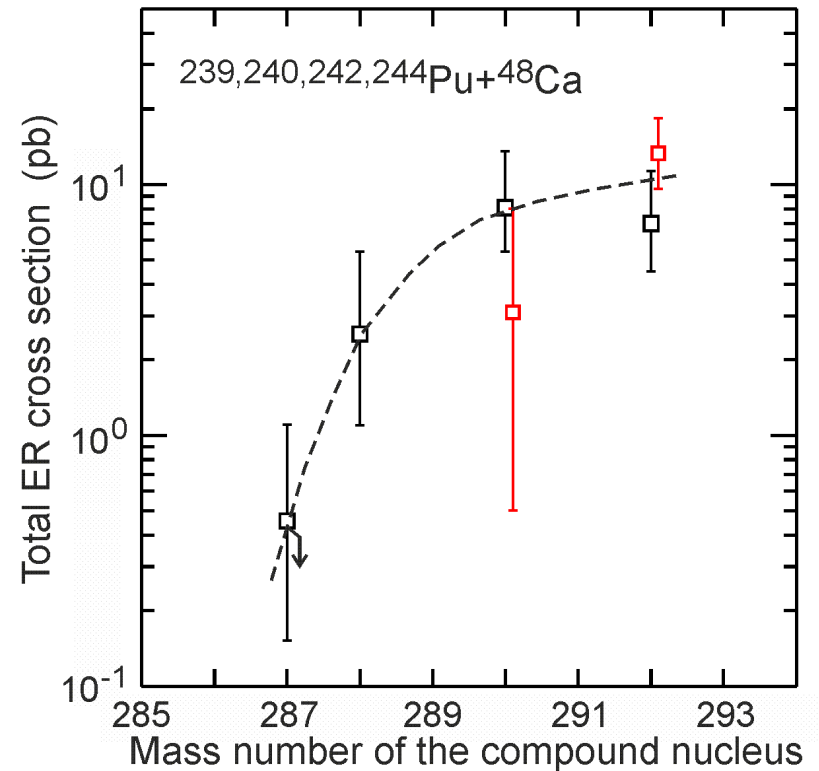
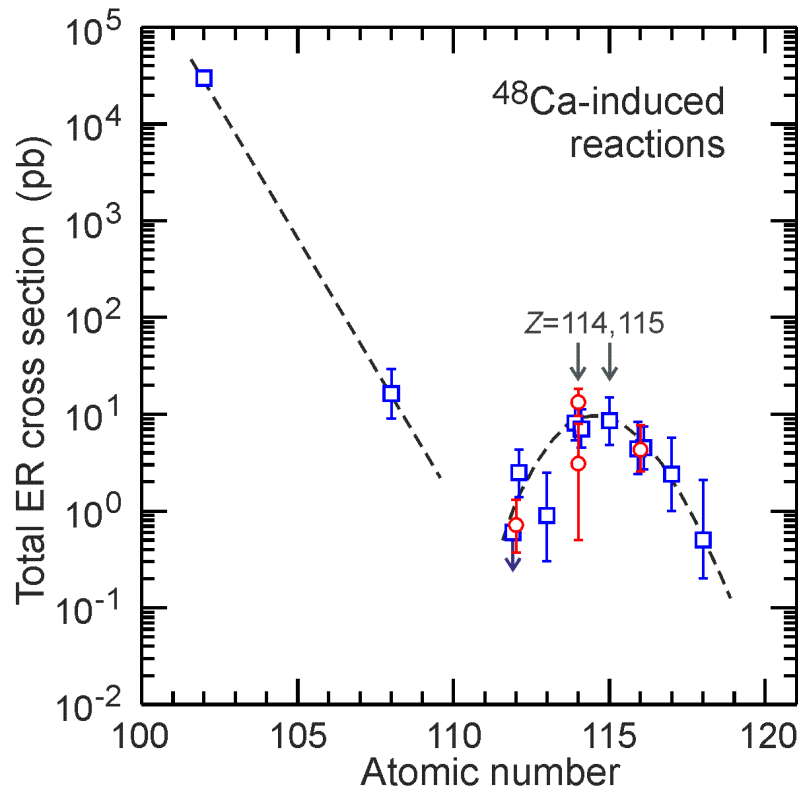
**Target** 0.51 mg/cm<sup>2</sup>  
**Energy of  $^{48}\text{Ca}$**  245 MeV  
**Excitation energy** 35.4 – 40.0 MeV  
**Beam dose**  $1.4 \cdot 10^{19}$



$$\sigma_{3n} = 0.23^{+0.59}_{-0.20} \text{ pb}$$



## Drop of production cross section with increase of $Z$ and decrease of $N$

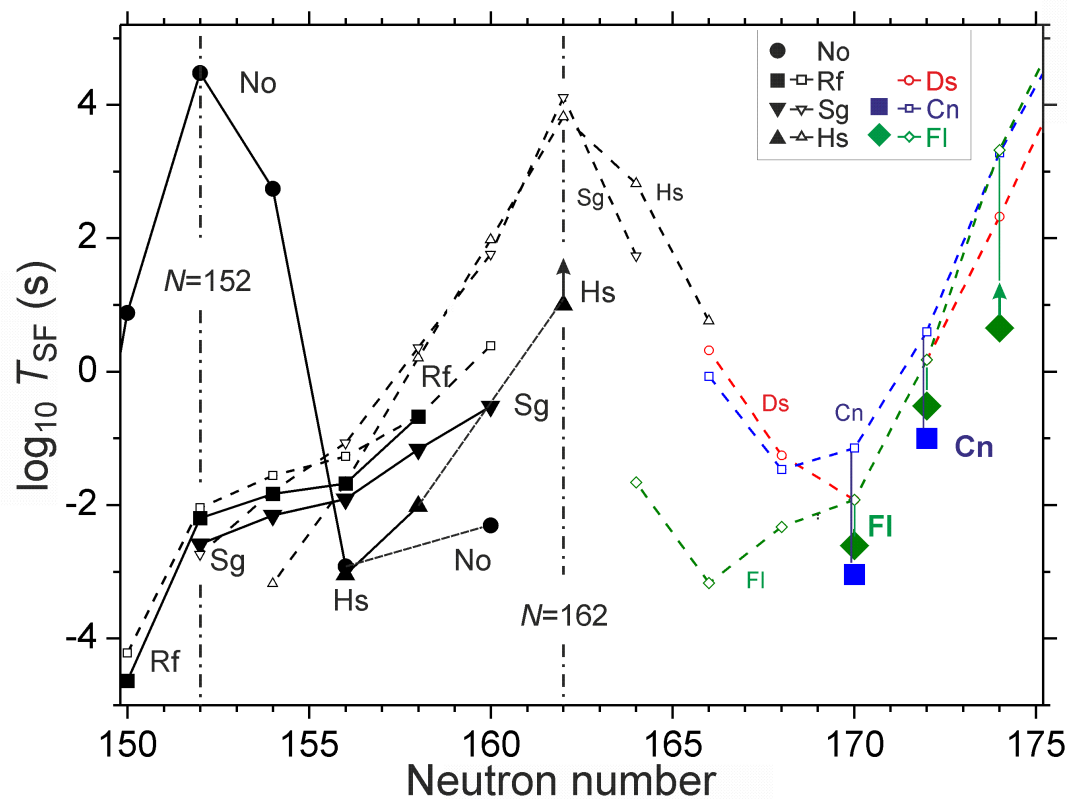


Approaching the border of region of SHN

Measured cross section is lower by factor of 20 than theoretical predictions and by factor of 50 than values measured in the reaction with  $^{244}\text{Pu}$ .  
Decrease of stability (fission barriers) of neutron-deficient FI isotopes.

SHE Factory

# Decrease of SF half-lives of even-even isotopes of Cn and Fl with receding magic number $N=184$

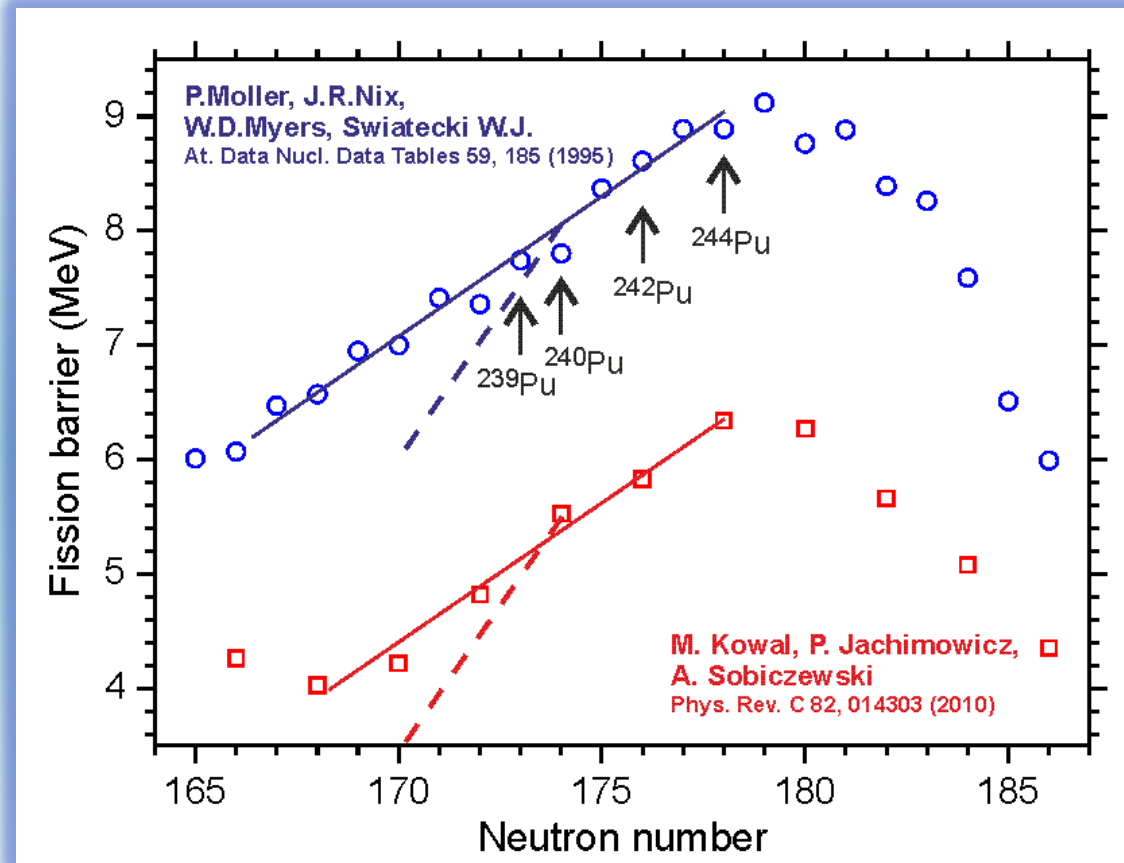


A. Sobiczewski

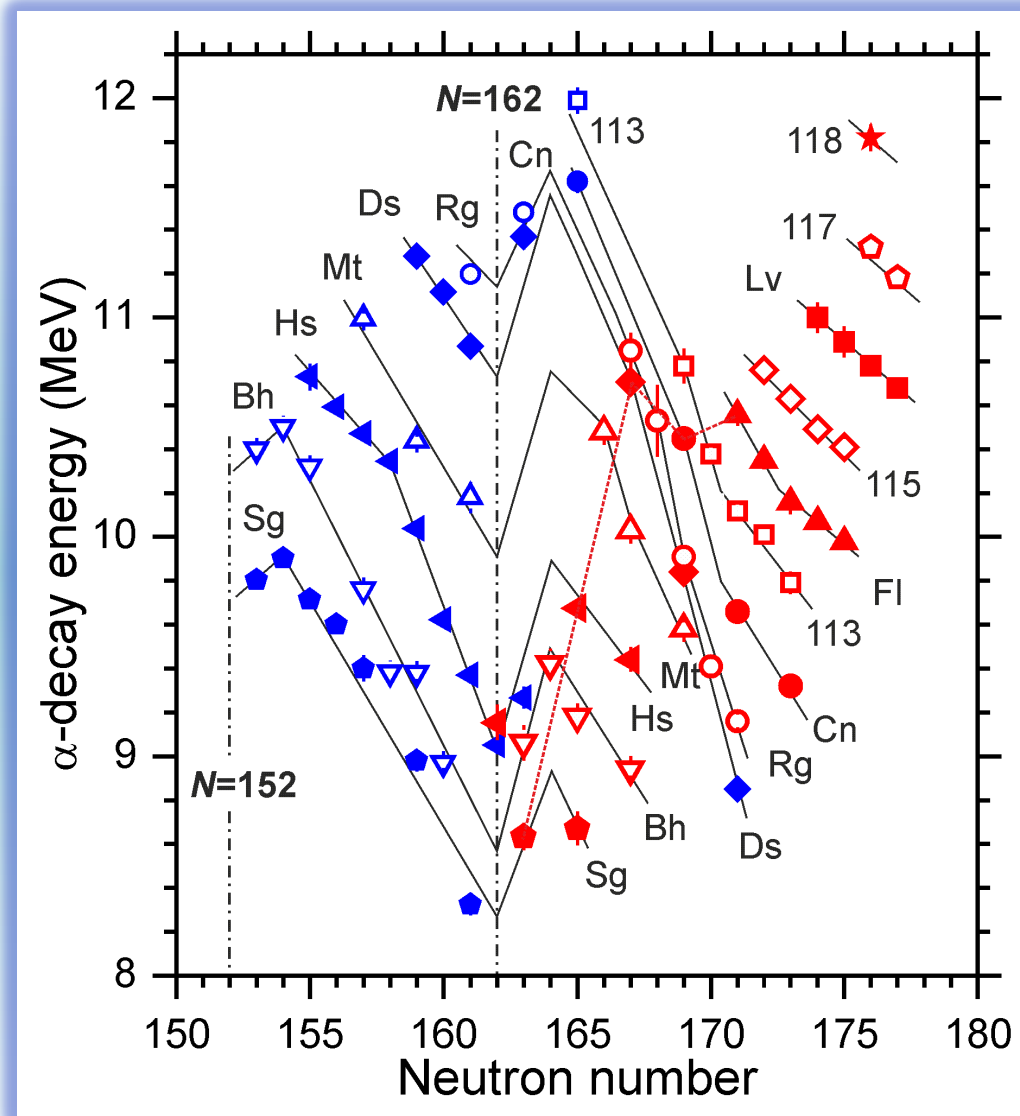
Approaching the border of region of SHN



# Decrease of SF half-lives of even-even isotopes of Cn and Fl with receding magic number $N=184$



## Increase of $Q_\alpha$ values for isotopes with $Z=112-114$



Approaching the border  
of region of SHN

## Conclusions:

New spontaneously fissioning isotope  $^{284}\text{Fl}$  was synthesized in the reactions of  $^{239}\text{Pu}$  and  $^{240}\text{Pu}$  with  $^{48}\text{Ca}$ .

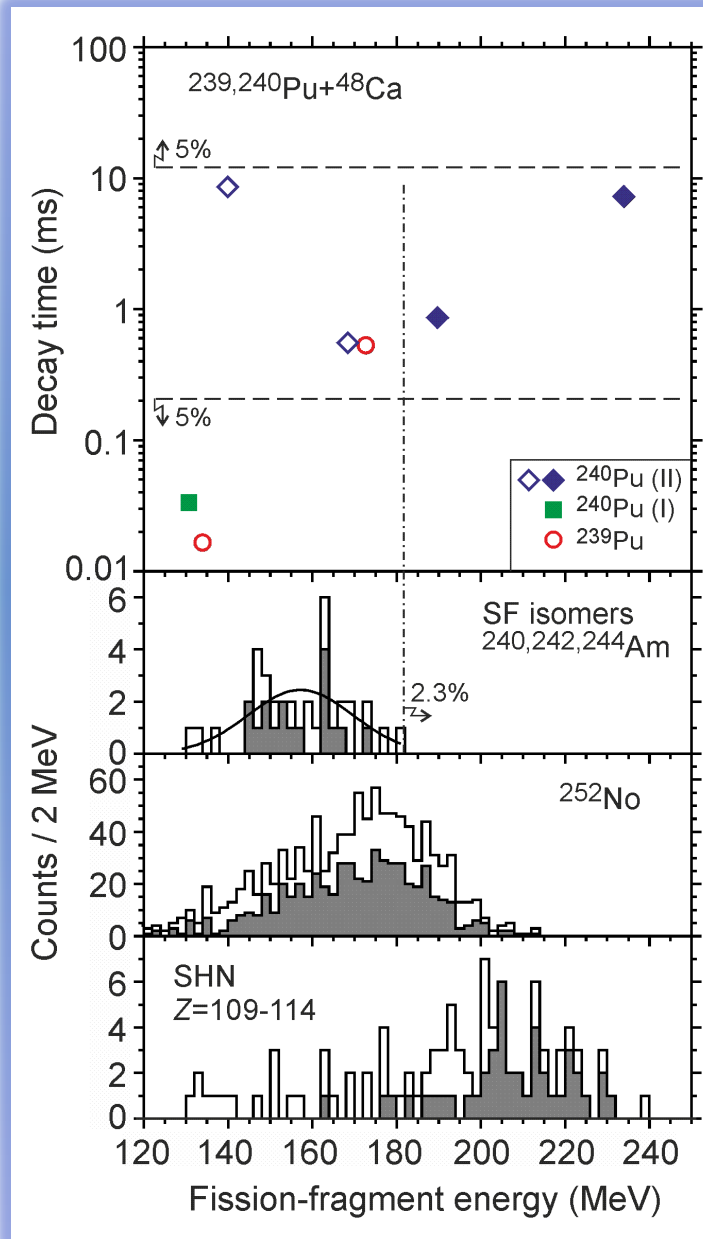
In the  $^{239}\text{Pu}+^{48}\text{Ca}$  reaction, the production cross section of 0.2 pb is 20 times lower than predicted value and 50 times lower than value measured in the reaction with  $^{244}\text{Pu}$ .

In the  $^{240}\text{Pu}+^{48}\text{Ca}$  reaction, three decay chains of  $^{285}\text{Fl}$  were observed. The  $\alpha$ -particle energy of  $^{285}\text{Fl}$  was measured for the first time. The decay properties of isotopes  $^{285}\text{Fl}$ ,  $^{281}\text{Cn}$ ,  $^{277}\text{Ds}$ ,  $^{273}\text{Hs}$ ,  $^{269}\text{Sg}$  and  $^{265}\text{Rf}$  were determined more precisely. The cross section of the reaction with  $^{240}\text{Pu}$  exceeds that for  $^{239}\text{Pu}$  by a factor of 10 but is 2-4 times lower than that for  $^{244}\text{Pu}$ .

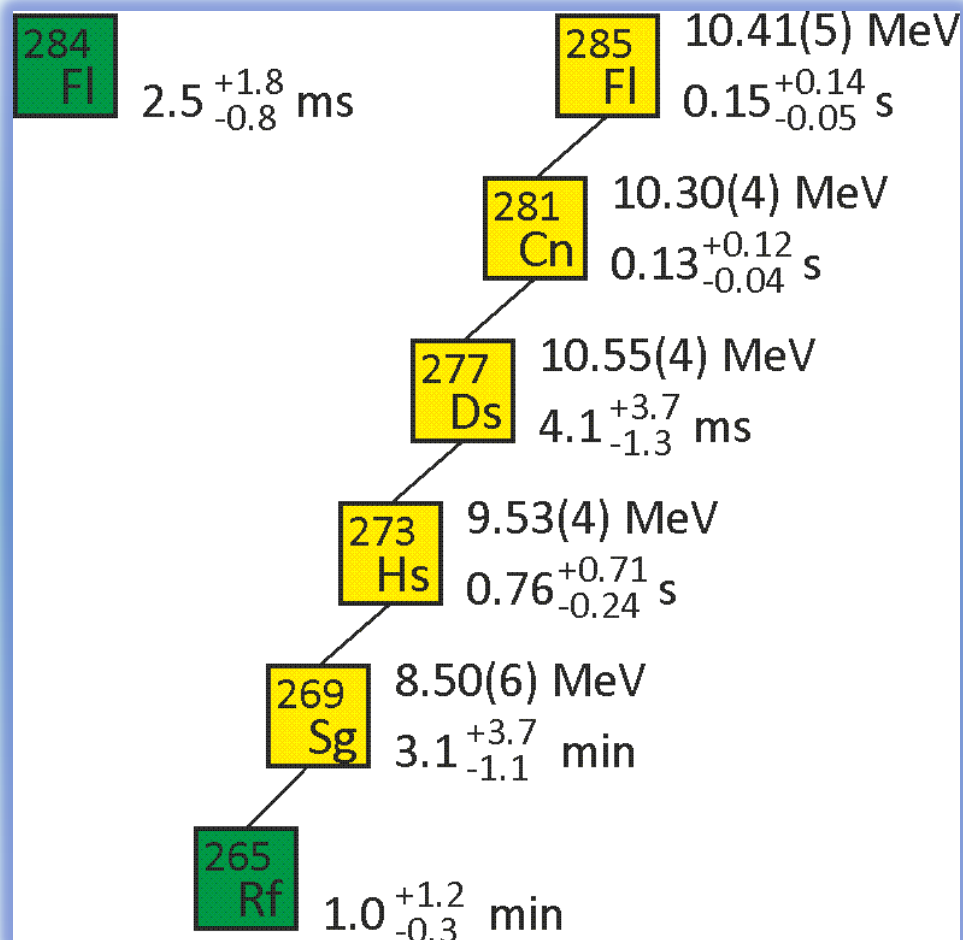
Considerable drop of the evaporation cross sections of the  $^{239}\text{Pu}+^{48}\text{Ca}$  and  $^{240}\text{Pu}+^{48}\text{Ca}$  reactions as well as decline of the half-life and dominance of the spontaneous fission over the  $\alpha$  decay for  $^{284}\text{Fl}$  and increased growth of the  $\alpha$ -decay energy of  $^{285}\text{Fl}$  compared to the heavier Fl isotopes indicate approaching the neutron-deficient border of stability of SHN.



# Origin of SF activity



## Decay properties of seven neutron-deficient nuclei



Alpha-particle energy of  $^{285}\text{Fl}$  and SF half-life of  $^{284}\text{Fl}$  were measured for the first time