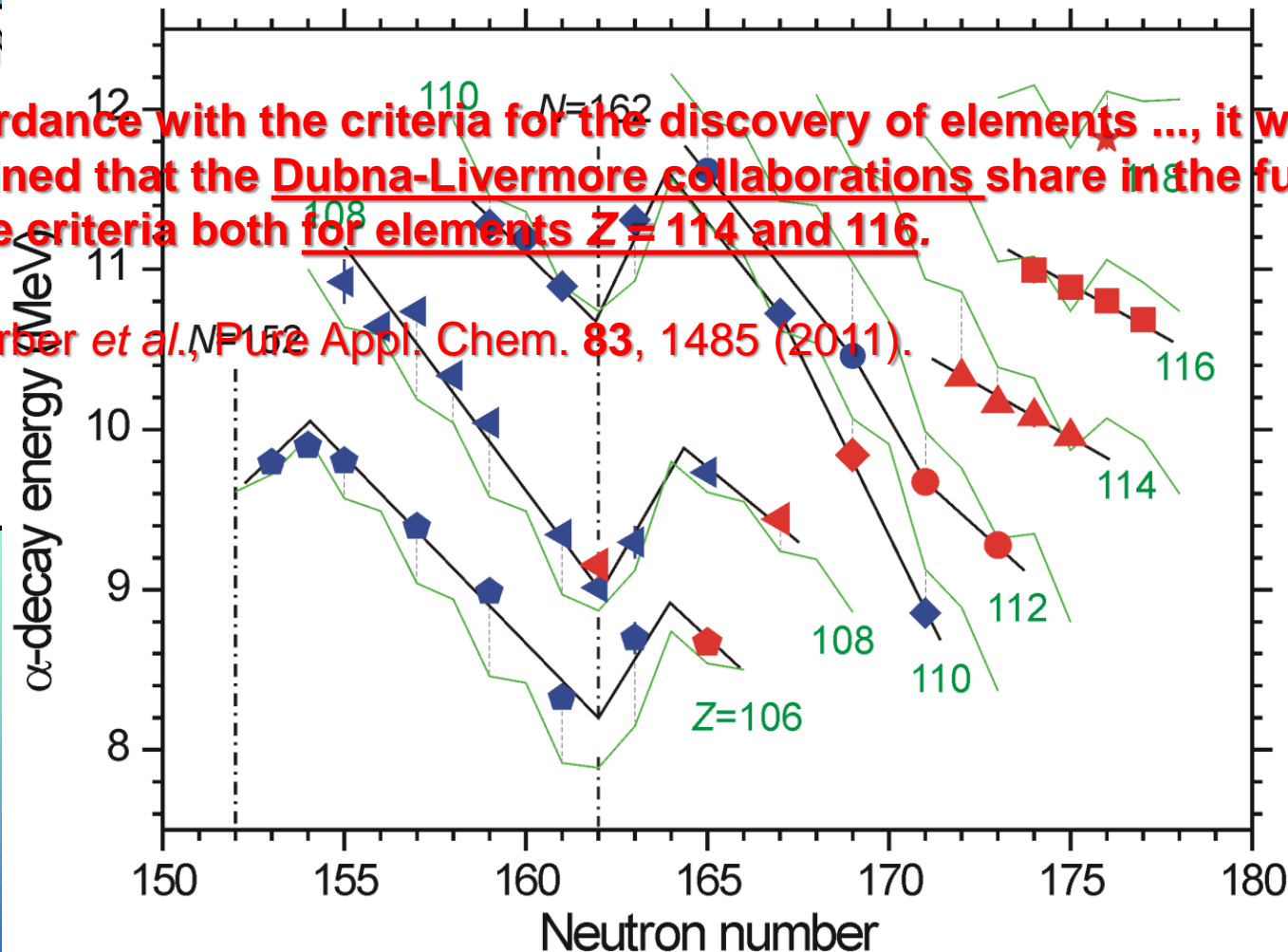


# Objective: additional identification of odd $Z=113$ , 115 and 117 nuclei

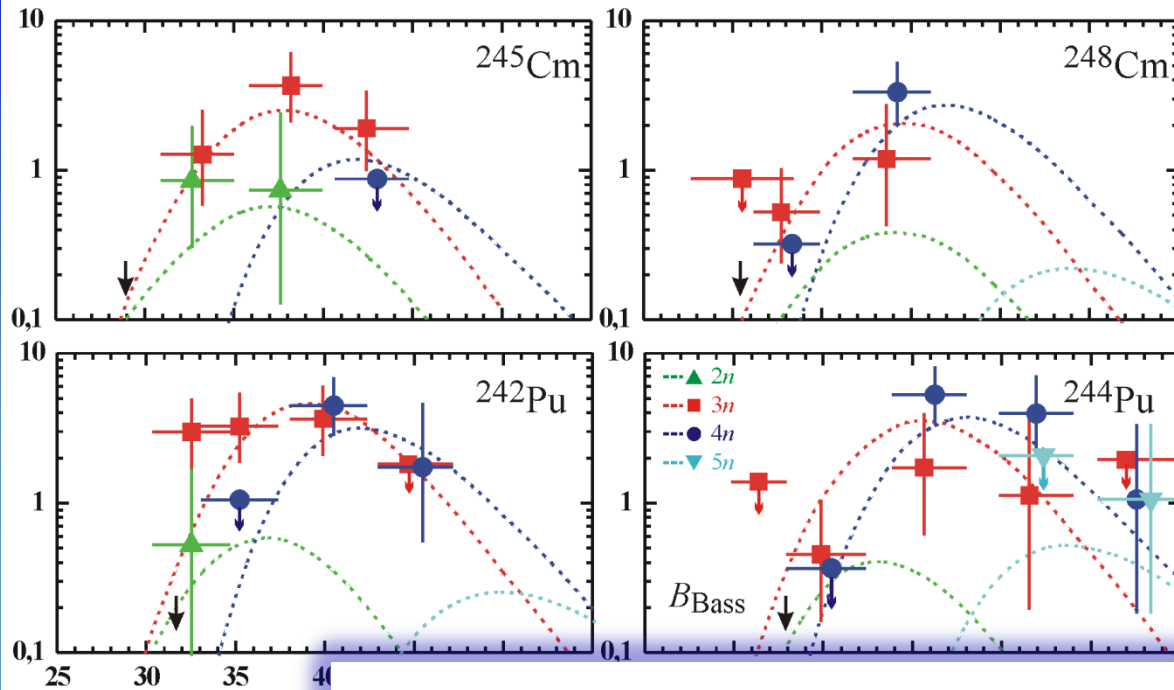
## Radioactive properties of even- $Z$ nuclei

In accordance with the criteria for the discovery of elements ..., it was determined that the Dubna-Livermore collaborations share in the fulfillment of those criteria both for elements  $Z = 114$  and 116.

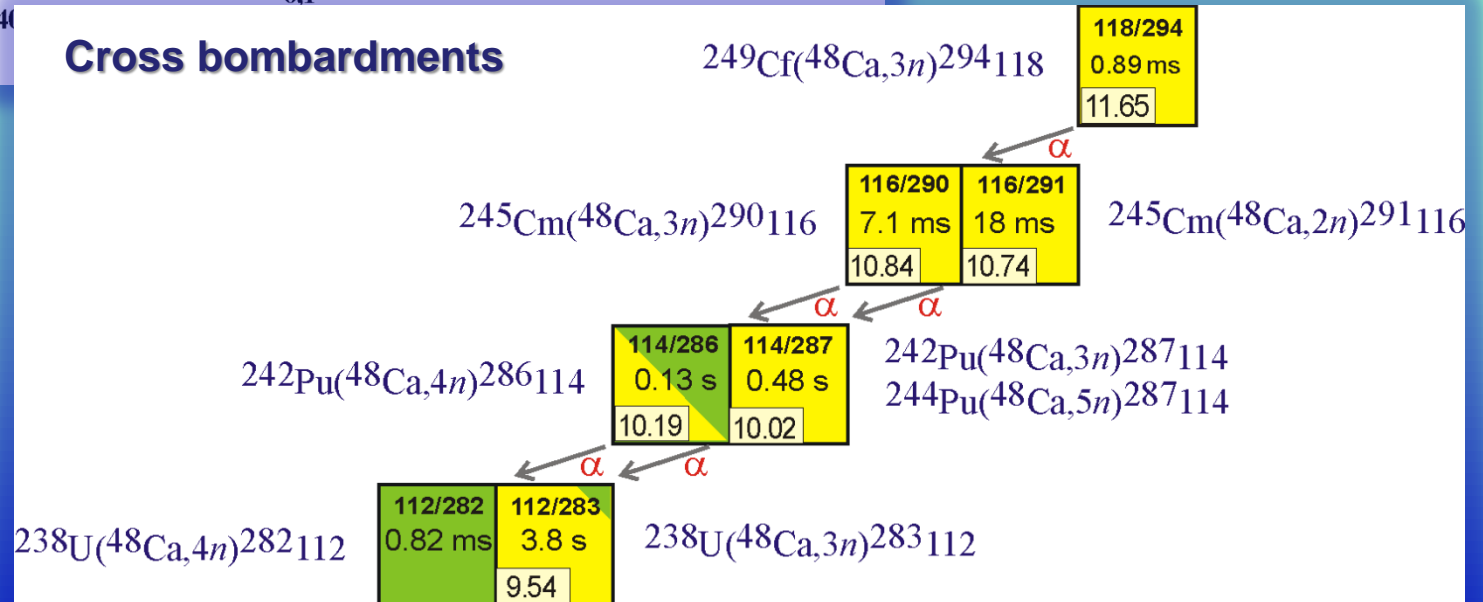
R.C. Barber *et al.*, *Pure Appl. Chem.* **83**, 1485 (2011).



# Production properties of even-Z nuclei: yield curve



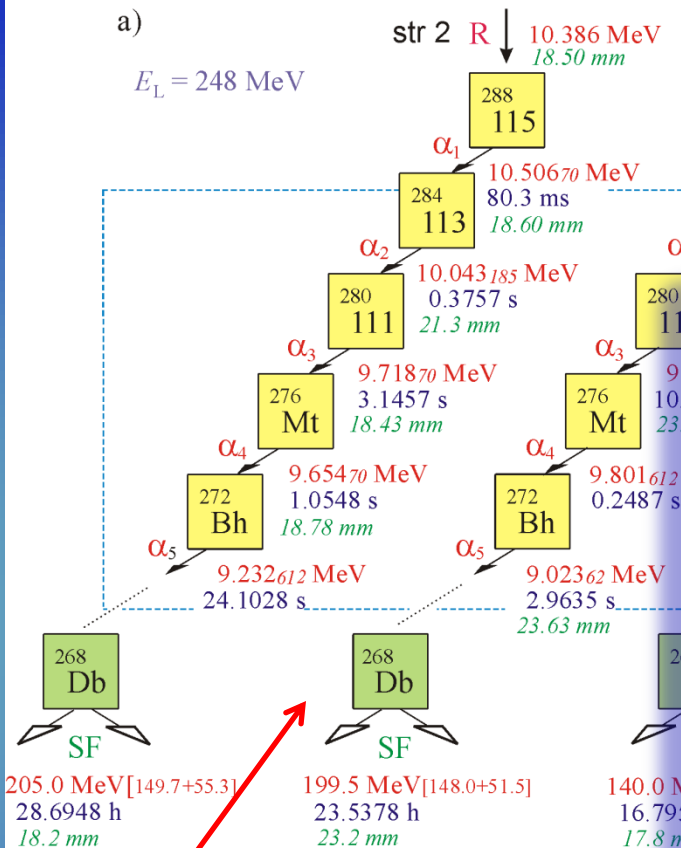
## Cross bombardments



$^{243}\text{Am} + ^{48}\text{Ca} / 2003$

a)

$E_L = 248 \text{ MeV}$



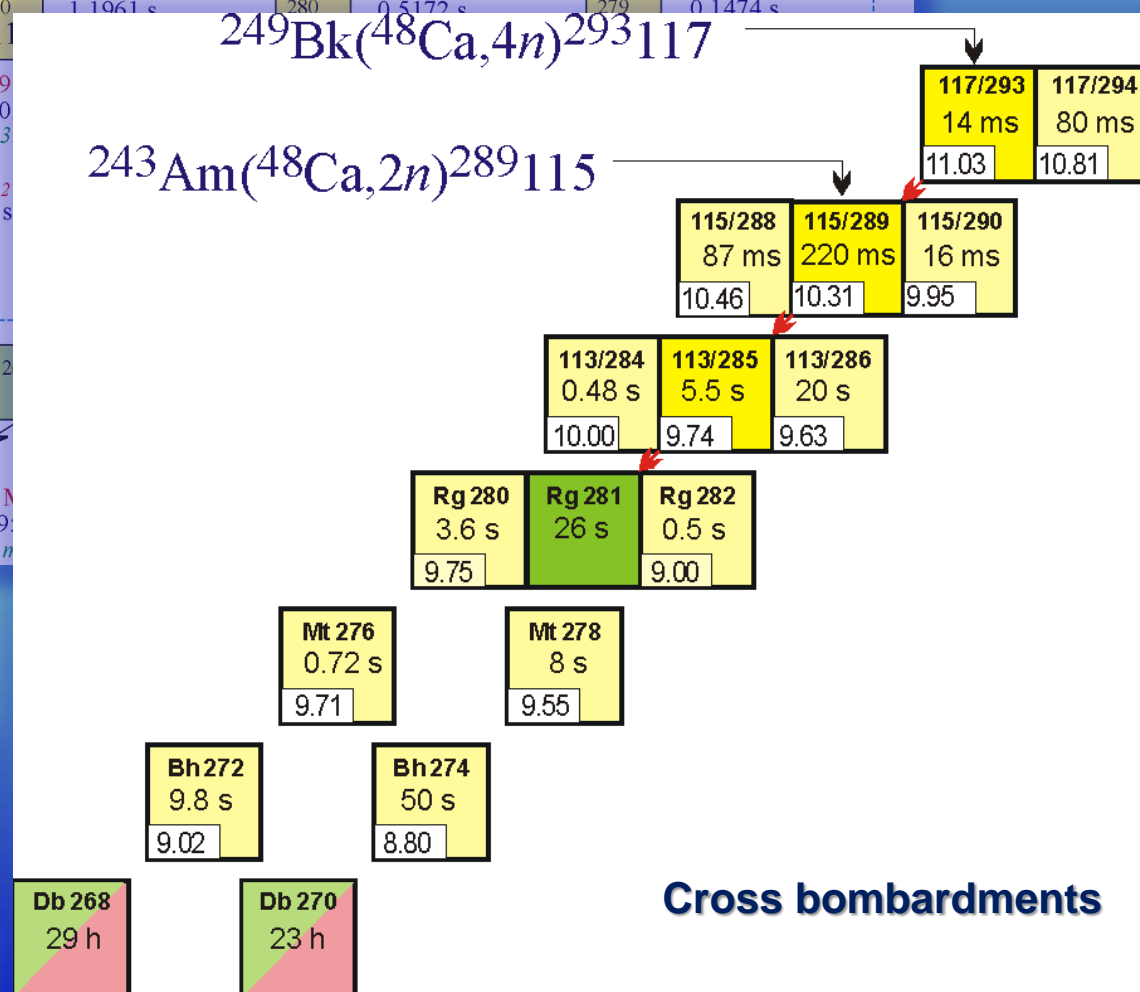
**chemical identification:  
group 5 element  $^{268}\text{Db}$**

1. More decay chains
2. Excitation function
3. Cross bombardments

b)

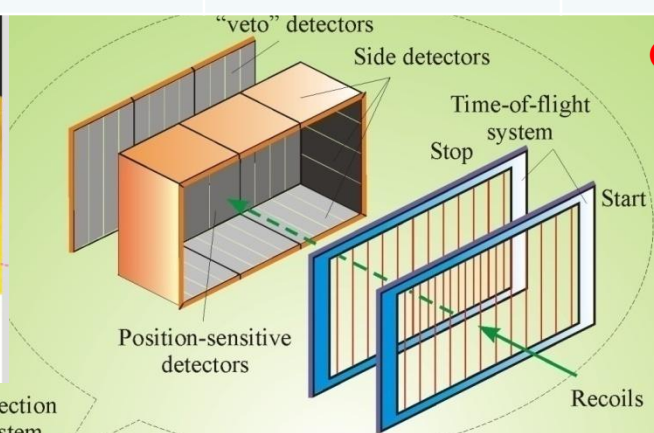
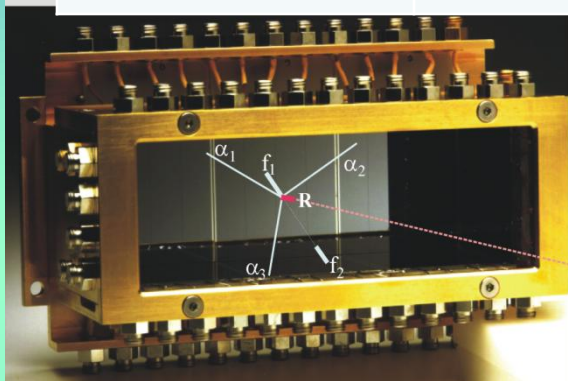
$^{249}\text{Bk}(^{48}\text{Ca},4n)^{293}117$

$^{243}\text{Am}(^{48}\text{Ca},2n)^{289}115$

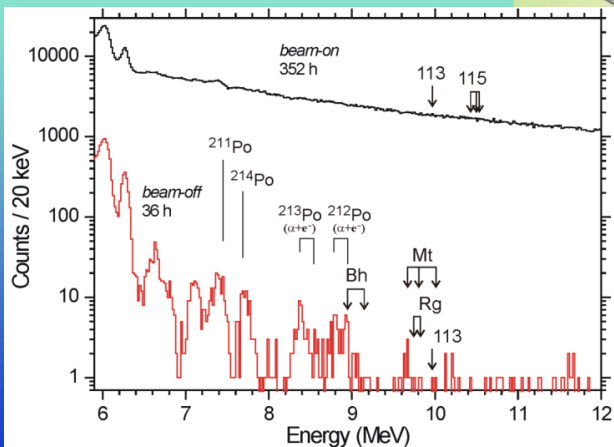
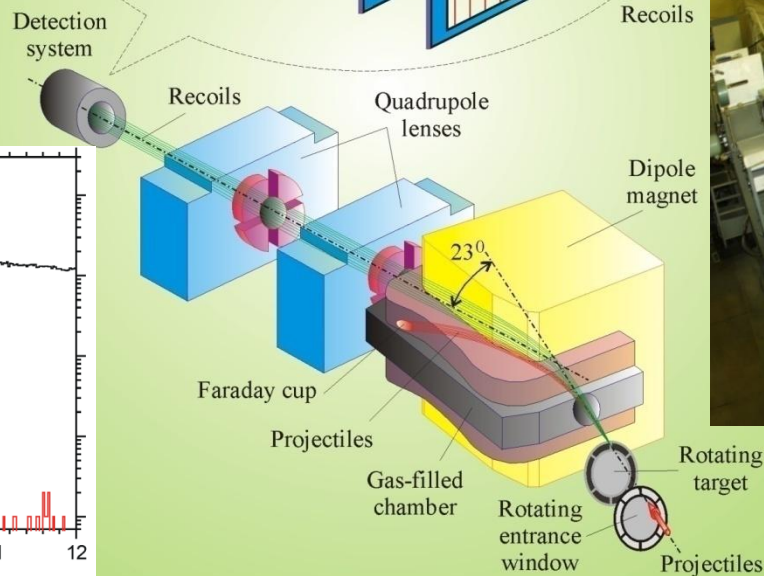
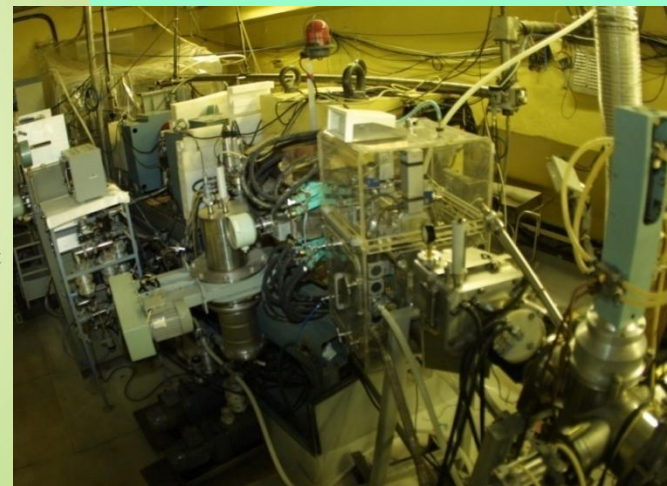


**Cross bombardments**

Target thickness mg/cm <sup>2</sup>	E lab (MeV)	E exc (MeV)	Beam dose x 10 <sup>18</sup>	Number of chains
0.37	248	38.0-42.3	3.7	3
0.37	243	34.0-38.3	3.3	6
0.37	240	31.1-35.3	11.7	7
0.84	241	31.4-36.2	4.8	5+1



## Gas-Filled Recoil Separator



$^{243}\text{Am} + ^{48}\text{Ca}$   
 $E^* = 40.3 \text{ MeV}$

str 10  
01:10 Nov. 07

str 6  
23:19 Nov. 16

str 4  
15:14 Nov. 27

$\alpha_1$

$\alpha_1$

$\alpha_1$

$\alpha_2$

$\alpha_2$

$\alpha_2$

$\alpha_3$

$\alpha_3$

$\alpha_3$

$\alpha_4$

$\alpha_4$

$\alpha_4$

$\alpha_5$

$\alpha_5$

$\alpha_5$

$^{288}_{115}$   $\leftarrow$   $^{291}_{115}$   
 $^{284}_{113}$  10.534 $_{103}$  MeV 11.476 MeV  
 94.2 ms 16.17 mm 16.18 mm

$^{288}_{115}$   $\leftarrow$   $^{291}_{115}$   
 $^{284}_{113}$  10.498 $_{86}$  MeV 13.080 MeV  
 238.4 ms 19.65 mm 18.18 mm

$^{288}_{115}$   $\leftarrow$   $^{291}_{115}$   
 $^{284}_{113}$  10.430 $_{76}$  MeV 11.852 MeV  
 879.0 ms 25.15 mm 25.09 mm

$^{280}\text{Rg}$  9.967 $_{156}$  MeV (2.913+7.054)  
 0.9001 s 16.32 mm

$^{280}\text{Rg}$  9.970 $_{86}$  MeV  
 1.3435 s 19.17 mm

$^{280}\text{Rg}$  9.83 $_{49}$  MeV (9.15+1/2\*1.36)  
 0.3662 s

$^{276}\text{Mt}$  9.826 $_{103}$  MeV  
 15.8352 s 16.21 mm

$^{276}\text{Mt}$  9.745 $_{86}$  MeV  
 3.8038 s 19.62 mm

$^{276}\text{Mt}$  missing  $\alpha$

$^{272}\text{Bh}$  10.012 $_{217}$  MeV (1.907+8.105)  
 2.8093 s 15.95 mm

$^{272}\text{Bh}$  9.805 $_{86}$  MeV  
 0.4938 s 19.41 mm

$^{272}\text{Bh}$  9.672 $_{76}$  MeV  
 1.7901 s 25.05 mm

$^{268}\text{Db}$  9.149 $_{103}$  MeV  
 18.8541 s 16.35 mm

$^{268}\text{Db}$  8.91 $_{44}$  MeV (8.30+1/2\*1.22)  
 36.9231 s

$^{268}\text{Db}$  8.948 $_{153}$  MeV (3.777+5.171)  
 4.7246 s 23.64 mm

217.3 (211.5+5.8) MeV  
 97.50 h  
 16.57 mm (beam-on)

1

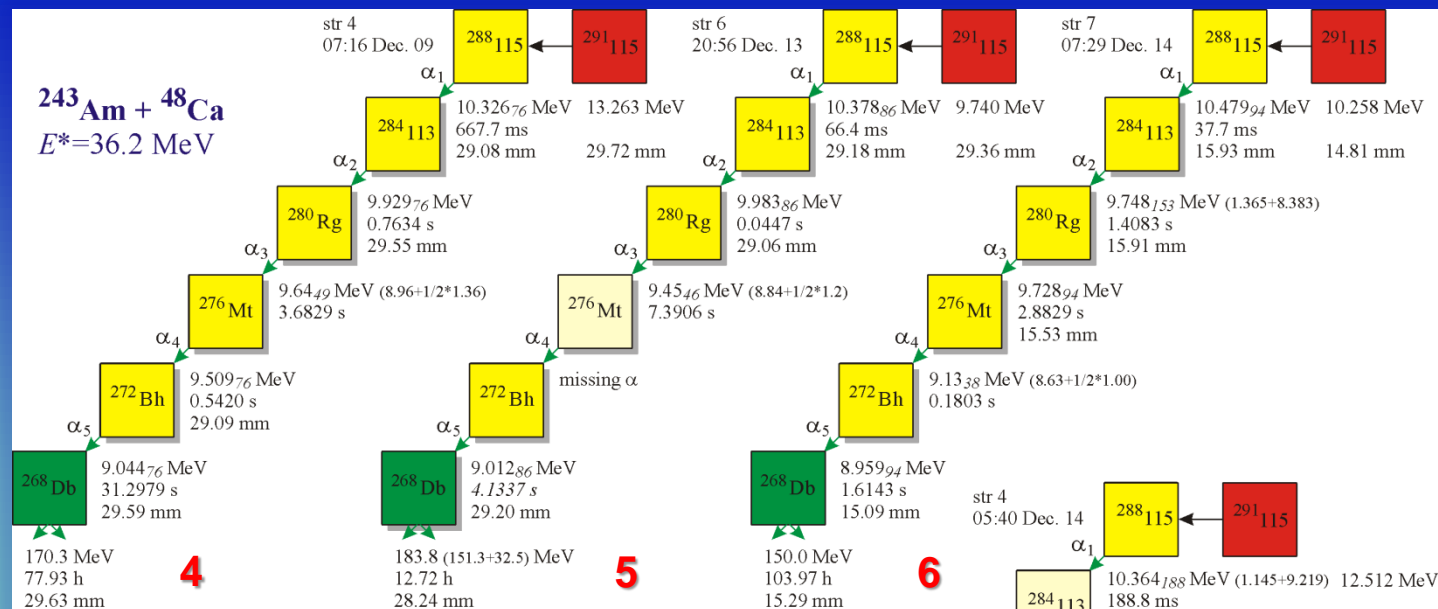
196.0 MeV  
 20.55 h  
 18.78 mm

2

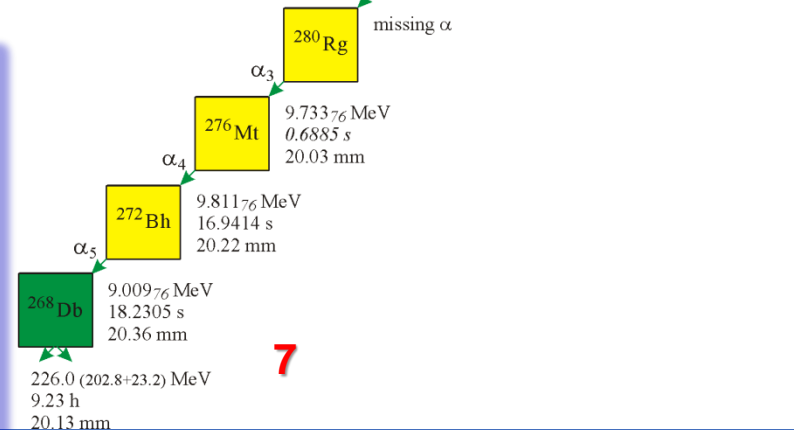
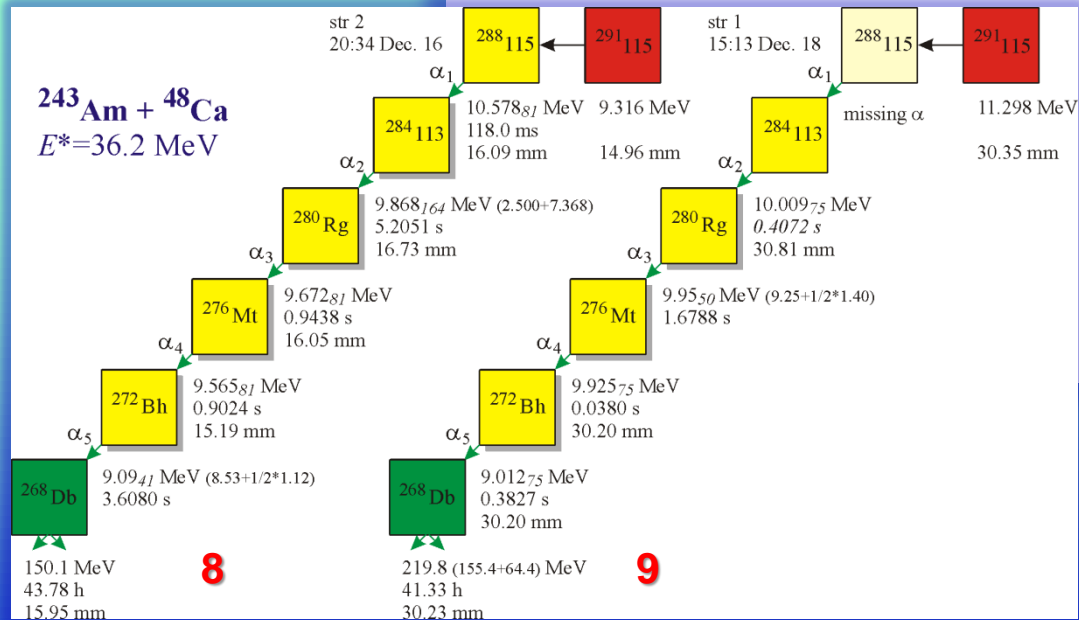
141.1 MeV  
 99.78 h  
 25.08 mm

3

$^{243}\text{Am} + ^{48}\text{Ca}$   
 $E^* = 36.2 \text{ MeV}$

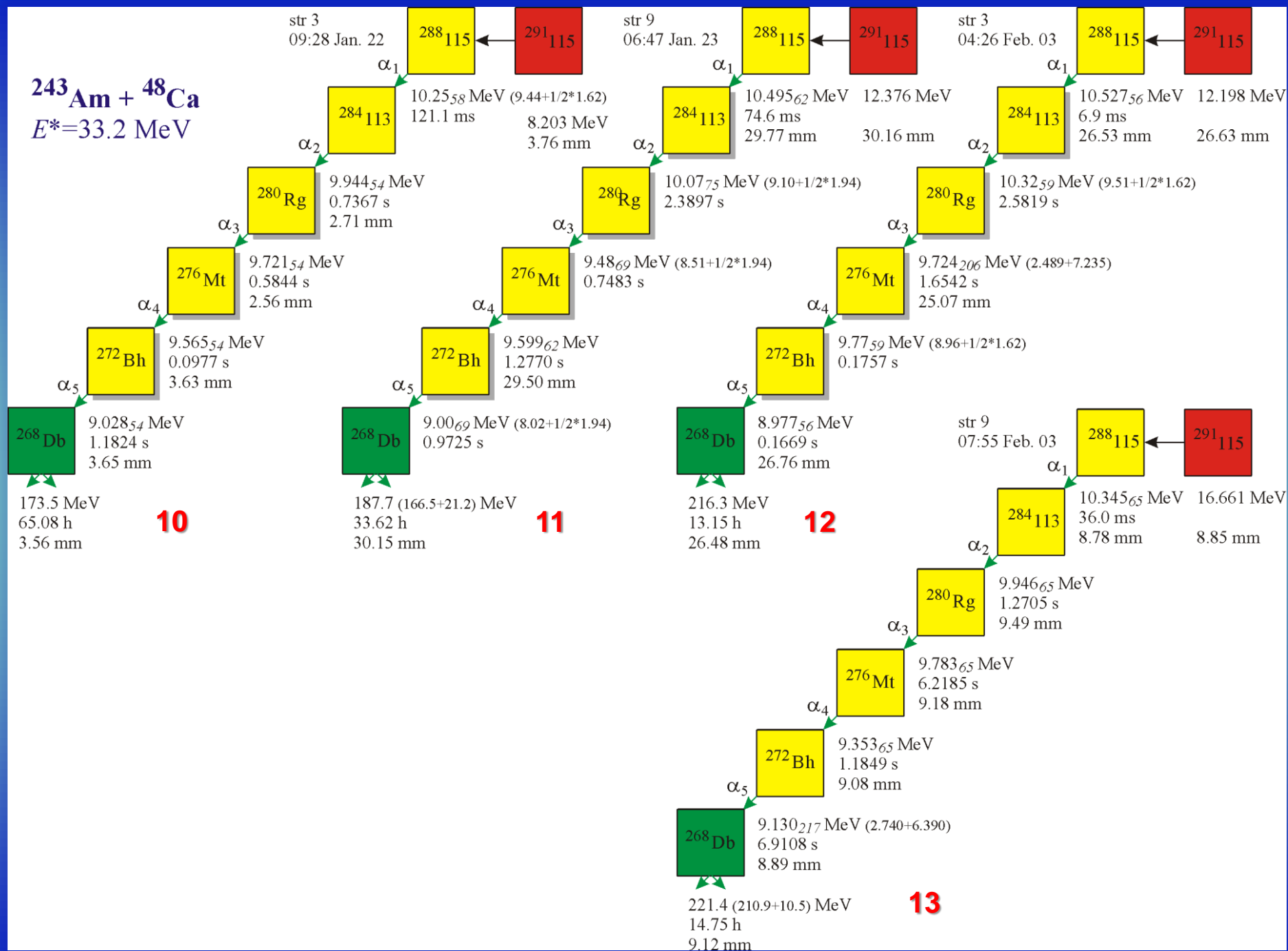


$^{243}\text{Am} + ^{48}\text{Ca}$   
 $E^* = 36.2 \text{ MeV}$



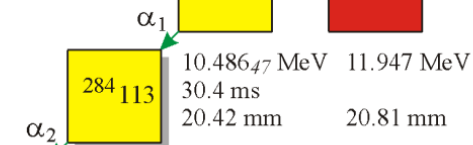


$^{243}\text{Am} + ^{48}\text{Ca}$   
 $E^* = 33.2 \text{ MeV}$



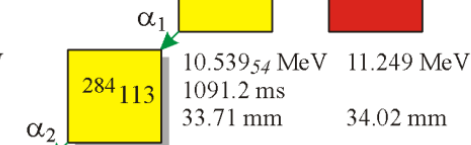
$^{243}\text{Am} + ^{48}\text{Ca}$   
 $E^* = 33.2 \text{ MeV}$

str 4  
 21:56 Feb. 03



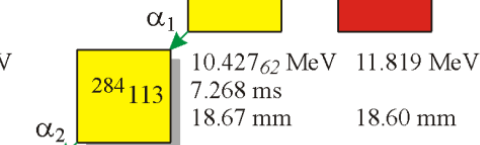
14

str 11  
 03:17 Feb. 09



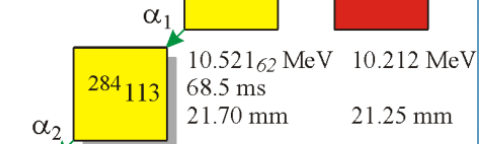
16

str 7  
 09:02 Feb. 25



15

str 5  
 05:17 Mar. 09



17

$^{243}\text{Am} + ^{48}\text{Ca}$   
 $E^* = 33.8 \text{ MeV}$



$^{243}\text{Am} + ^{48}\text{Ca}$   
 $E^* = 33.8 \text{ MeV}$

str 5  
 16:06 Mar. 13

$\alpha_1$

$^{288}_{115}$   
 $^{284}_{113}$

$\alpha_2$

$^{280}\text{Rg}$   
 $^{276}\text{Mt}$

$^{272}\text{Bh}$   
 $^{268}\text{Db}$

18

str 3  
 23:46 Mar. 30

$\alpha_1$

$^{289}_{115}$   
 $^{285}_{113}$

$\alpha_2$

$^{281}\text{Rg}$

215.7 MeV  
 1.9775 s  
 15.09 mm

10.496<sub>62</sub> MeV 10.477 MeV  
 768.0 ms 11.06 mm 11.87 mm

$^{280}\text{Rg}$   
 $^{276}\text{Mt}$

$^{272}\text{Bh}$   
 $^{268}\text{Db}$

19

211.9 (207.5+4.4) MeV

**2n channel !**

str 4  
 00:07 Mar. 17

$\alpha_1$

$^{288}_{115}$   
 $^{284}_{113}$

$\alpha_2$

$^{280}\text{Rg}$   
 $^{276}\text{Mt}$

$^{272}\text{Bh}$   
 $^{268}\text{Db}$

20

205.1 (183.1+22.0) MeV  
 23.07 h  
 21.53 mm

str 6  
 04:10 Mar. 17

$\alpha_1$

$^{288}_{115}$   
 $^{284}_{113}$

$\alpha_2$

$^{280}\text{Rg}$   
 $^{276}\text{Mt}$

$^{272}\text{Bh}$   
 $^{268}\text{Db}$

21

189.3 (176.8+12.5) MeV  
 3.348 h  
 28.69 mm

10.558<sub>50</sub> MeV 12.108 MeV  
 33.3 ms 15.99 mm

$^{280}\text{Rg}$   
 $^{276}\text{Mt}$

$^{272}\text{Bh}$   
 $^{268}\text{Db}$

str 5  
 20:08 Mar. 25

$\alpha_1$

$^{288}_{115}$   
 $^{284}_{113}$

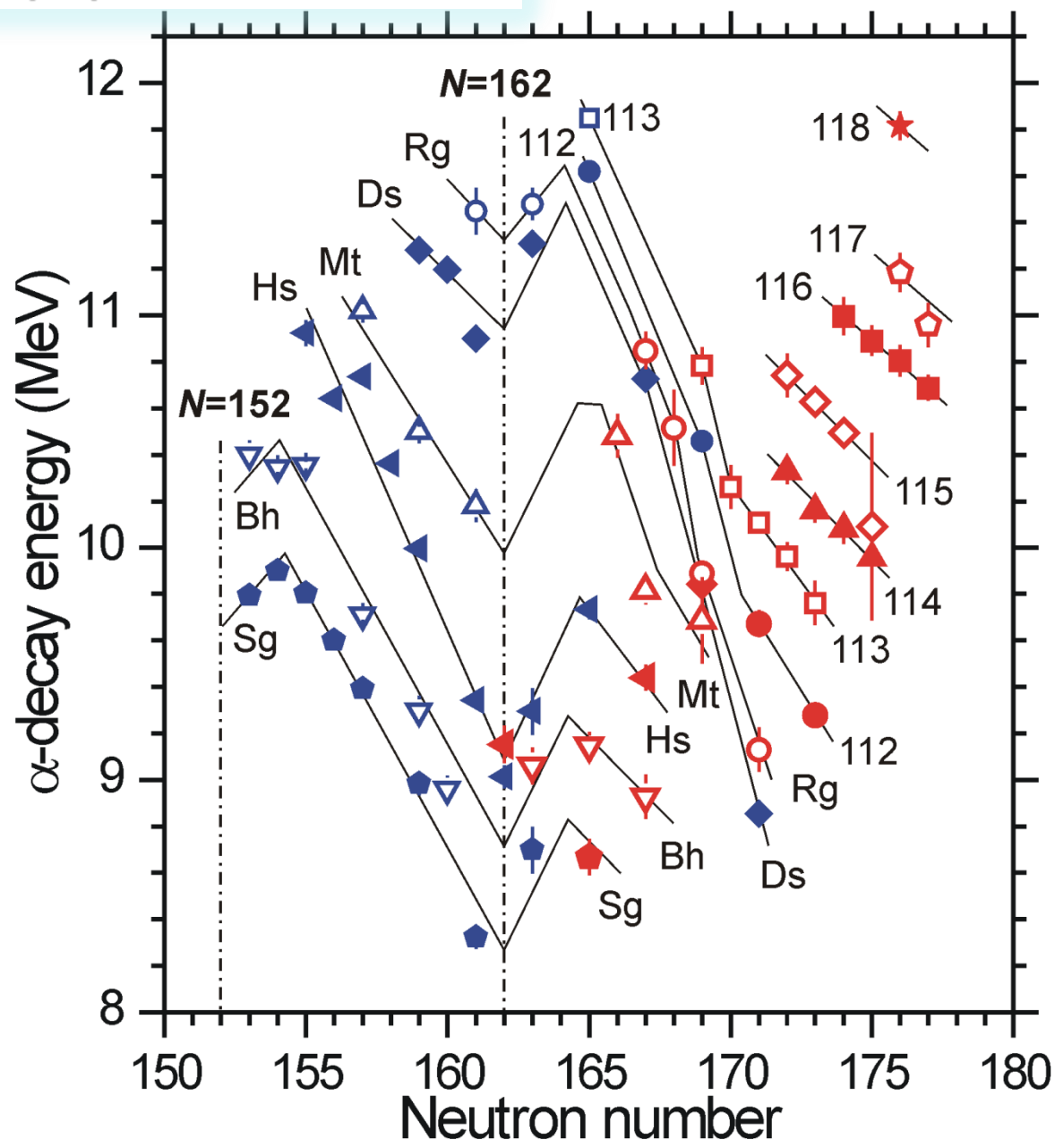
missing  $\alpha$  11.808 MeV  
 28.25 mm

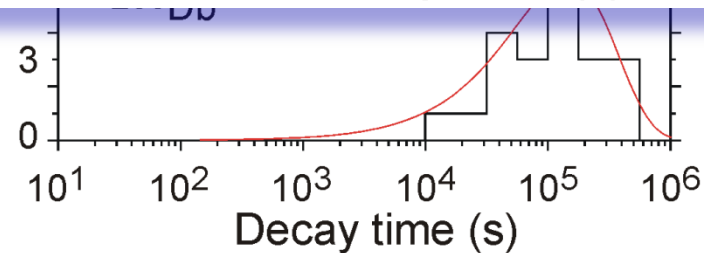
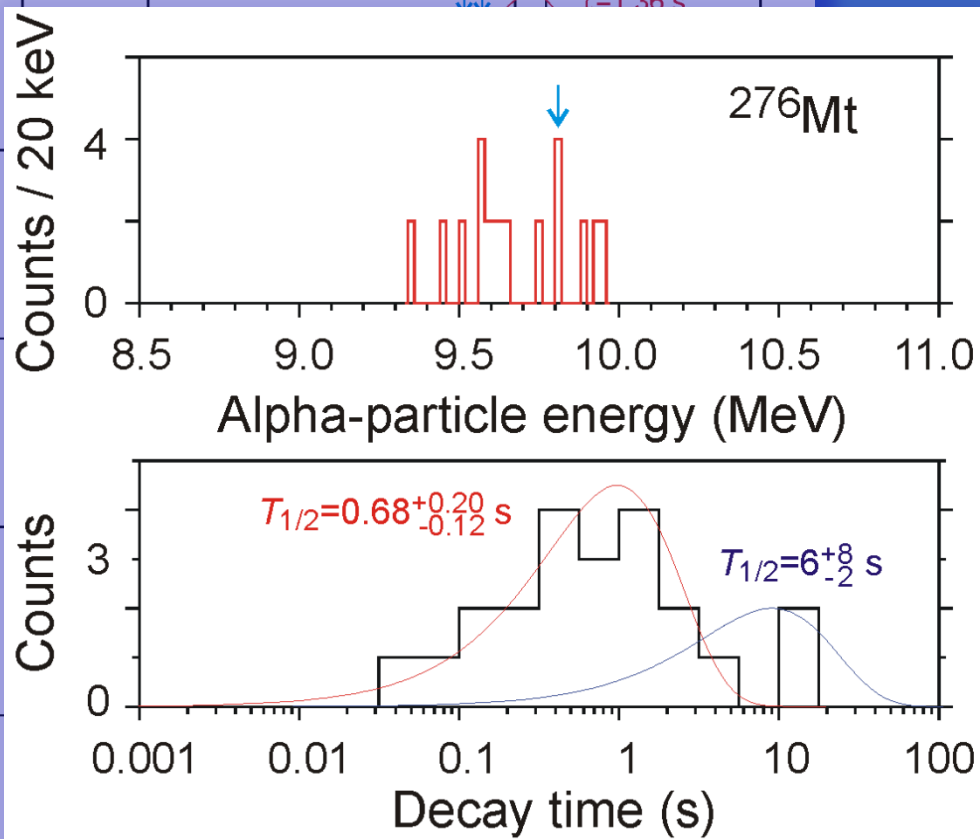
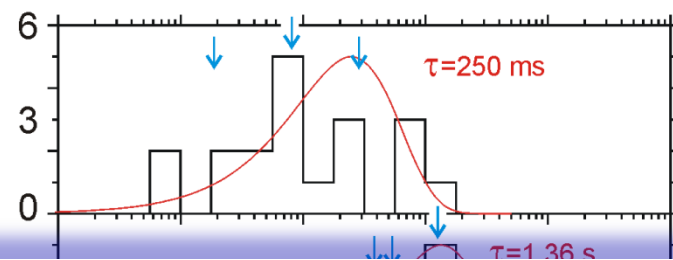
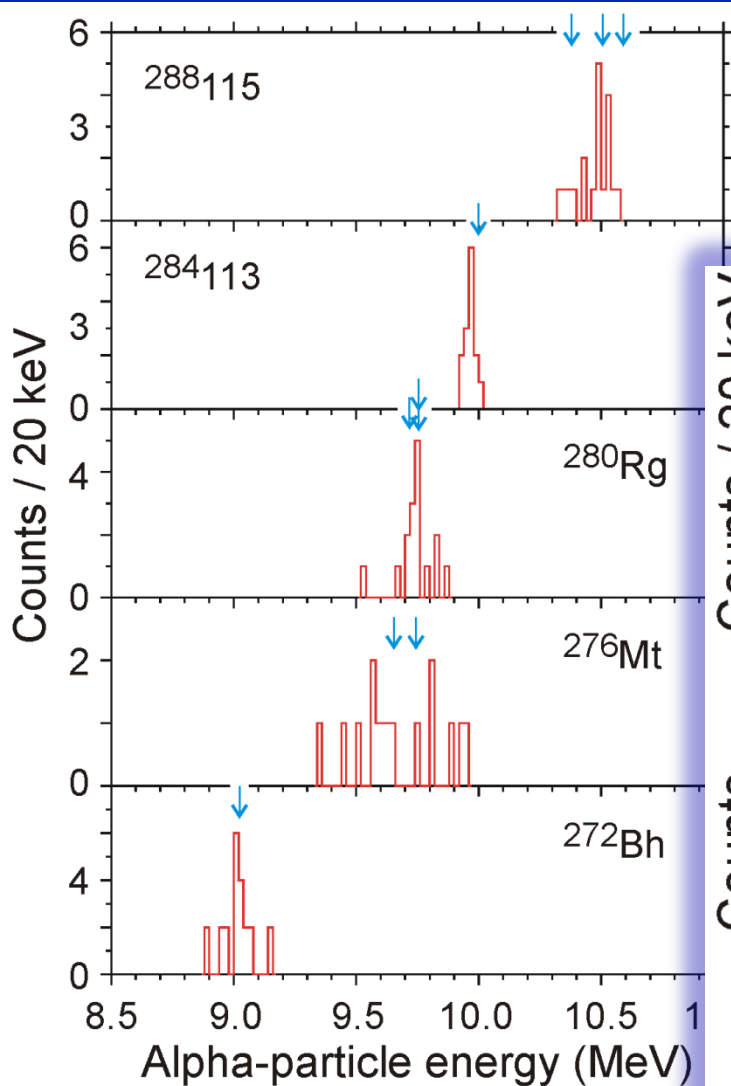
$^{280}\text{Rg}$   
 $^{276}\text{Mt}$

$^{272}\text{Bh}$   
 $^{268}\text{Db}$

missing  $\alpha$

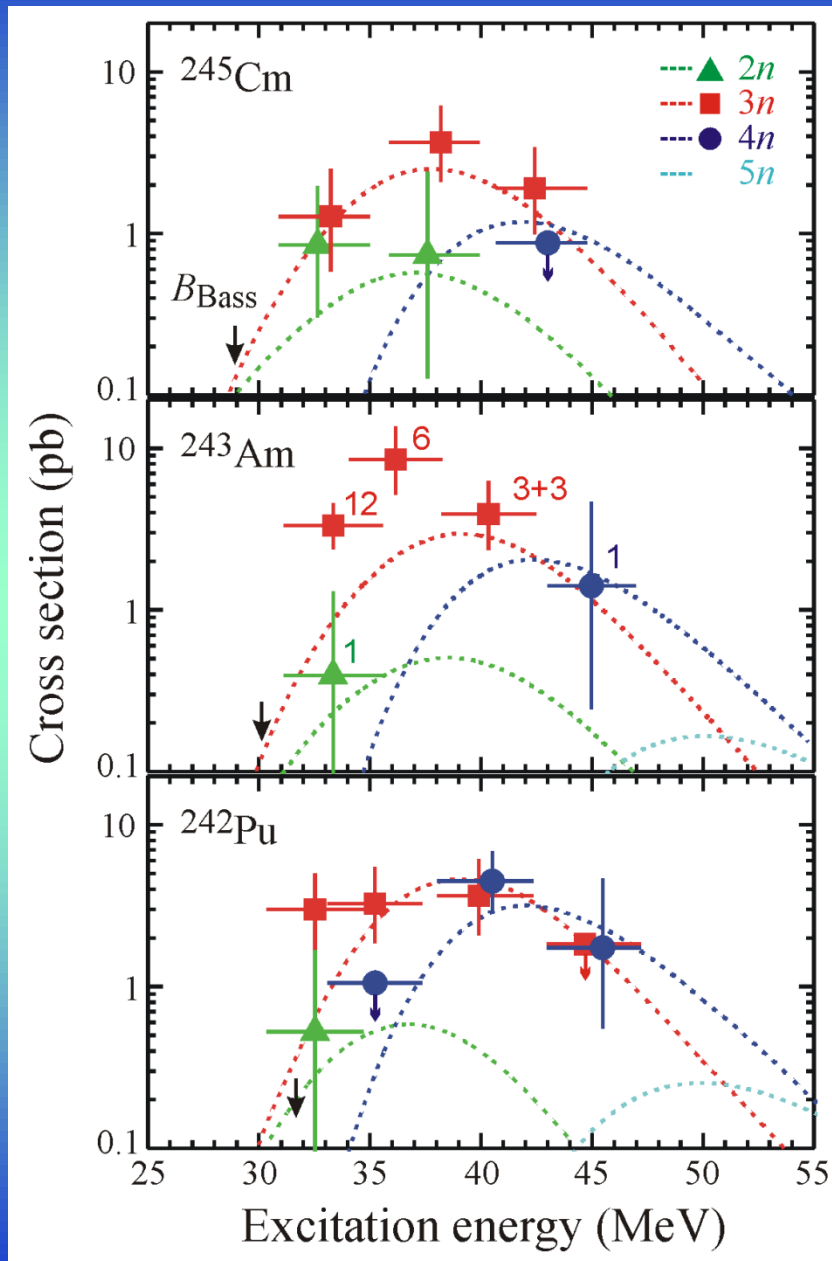
## Radioactive properties of odd-Z nuclei

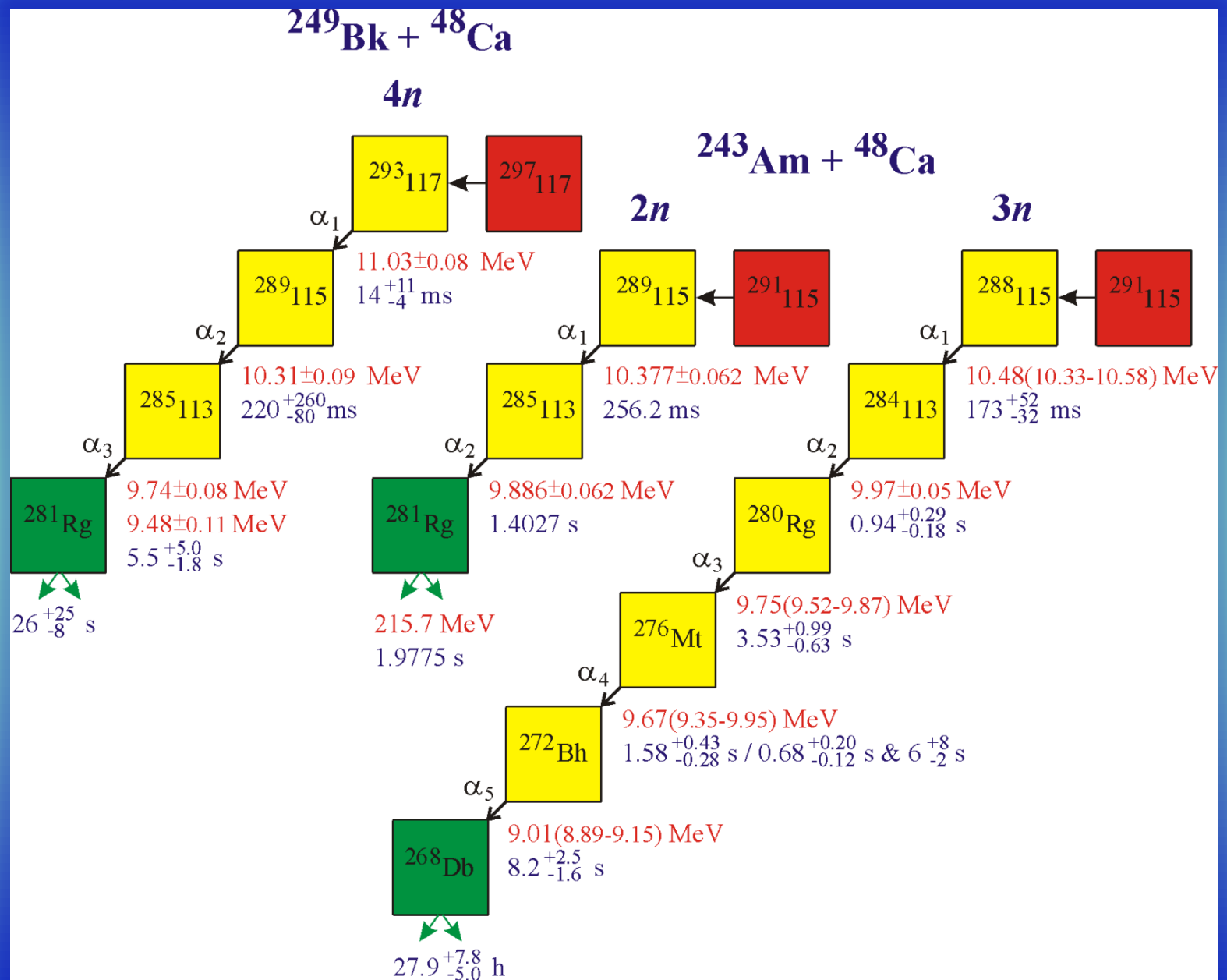




**Radioactive properties of odd-Z nuclei**

## Production properties of odd-Z nuclei: yield curve





## Summary:

Discovery of elements 113 and 115 produced in 2003 was confirmed by observation of 21 new decay chains originating from  $^{288}\text{115}$ , the product of the  $3n$ -evaporation channel of the reaction  $^{243}\text{Am}+^{48}\text{Ca}$ .

Decay properties of all the six nuclei  $^{288}\text{115}$ ,  $^{284}\text{113}$ ,  $^{280}\text{Rg}$ ,  $^{276}\text{Mt}$ ,  $^{272}\text{Bh}$ , and  $^{268}\text{Db}$  synthesized in 2003 are in full agreement with those measured in the recent experiments.

Excitation function of the reaction  $^{243}\text{Am}+^{48}\text{Ca}$  was measured at three lower projectile energies. Experiments are to be continued.

Discovery of element 117 was confirmed by registration of the decay chain of  $^{289}\text{115}$  which was produced for the first time in the reaction  $^{249}\text{Bk}(^{48}\text{Ca},4n)$  as the descendant nucleus of  $^{293}\text{117}$ . The isotope  $^{289}\text{115}$  was synthesized in two cross bombardments.



Yu.Ts. Oganessian,<sup>1</sup> F.Sh. Abdullin,<sup>1</sup> S.N. Dmitriev,<sup>1</sup> J. M. Gostic,<sup>2</sup> J. H. Hamilton,<sup>3</sup> R.A. Henderson,<sup>2</sup> M.G. Itkis,<sup>1</sup> A.N. Mezentsev,<sup>1</sup> K.J. Moody,<sup>2</sup> A.N. Polyakov,<sup>1</sup> A.V. Ramayya,<sup>3</sup> J.B. Roberto,<sup>2</sup> K.P. Rykaczewski,<sup>2</sup> R.N. Sagaidak,<sup>1</sup> D.A. Shaughnessy,<sup>2</sup> I.V. Shirokovsky,<sup>1</sup> M.A. Stoyer,<sup>2</sup> V.G. Subbotin,<sup>1</sup> A.M. Sukhov,<sup>1</sup> E. E. Tereshatov,<sup>1,2</sup> Yu.S. Tsyganov,<sup>1</sup> V.K. Utyonkov,<sup>1</sup> A.A. Voinov,<sup>1</sup> and G.K. Vostokin<sup>1</sup>

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<sup>2</sup>Lawrence Livermore National Laboratory, Livermore, California 94551, USA

<sup>3</sup>Department of Physics and Astronomy, Vanderbilt University, Nashville, Tennessee 37235, USA

<sup>4</sup>Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831, USA



Z = 114

176 178 180 182 184



**115/288**  
173 ms  
10.33-10.58



114/285 0.08 s	114/286 0.13 s	114/287 0.48 s	114/288 0.80 s	114/289 2.6 s
	10.19	10.02	9.94	9.82

**113/284**  
0.94 s  
9.97

*p4n p3n p2n p1n*

112/281 70 ms 10.3	112/282 0.82 ms	112/283 3.8 s 9.54	112/284 97 ms 9.15	112/285 29 s
--------------------------	--------------------	--------------------------	--------------------------	-----------------

**Rg280**  
3.5 s  
9.52-9.87

**Ds279**  
0.20 s  
9.70

**Ds281**  
11 s

**Ds277**  
4 ms  
10.57

**Mt276**  
1.6 s  
9.35-9.95

**Hs275**  
0.19 s  
9.30

**Hs277**  
3 ms

**Hs273**  
0.17 s  
9.59

**Bh272**  
8.2 s  
8.89-9.15

**Sg271**  
1.9 m  
8.54

**Sg269**  
90 s  
8.57

**Db268**  
27 h

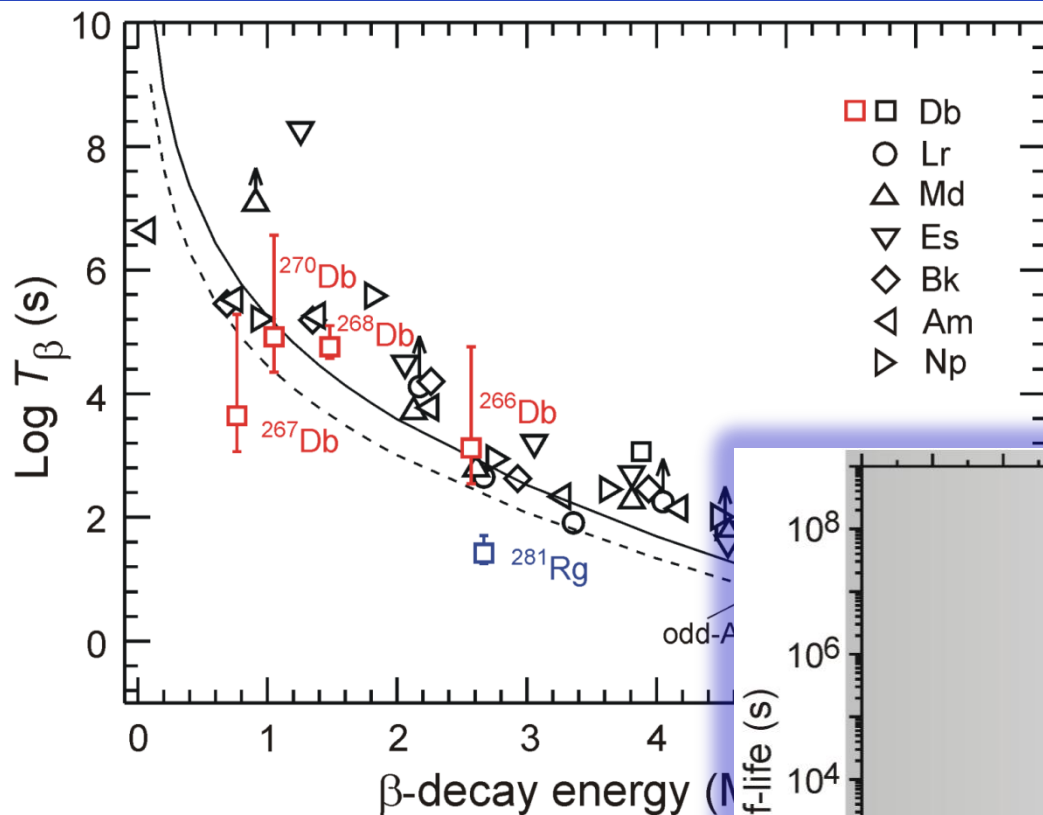
**Rf267**  
1.3 h



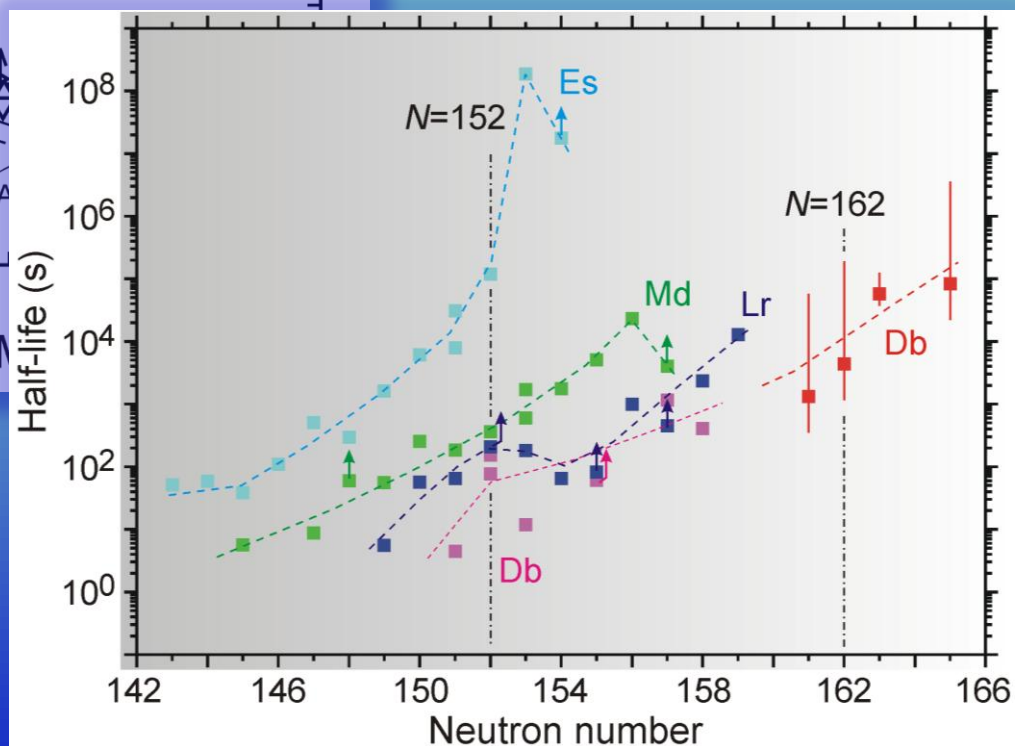
~~*pxn channel*~~

Future experiments: excitation function  
identification of Z by X-rays of  $^{268}\text{Rf}$

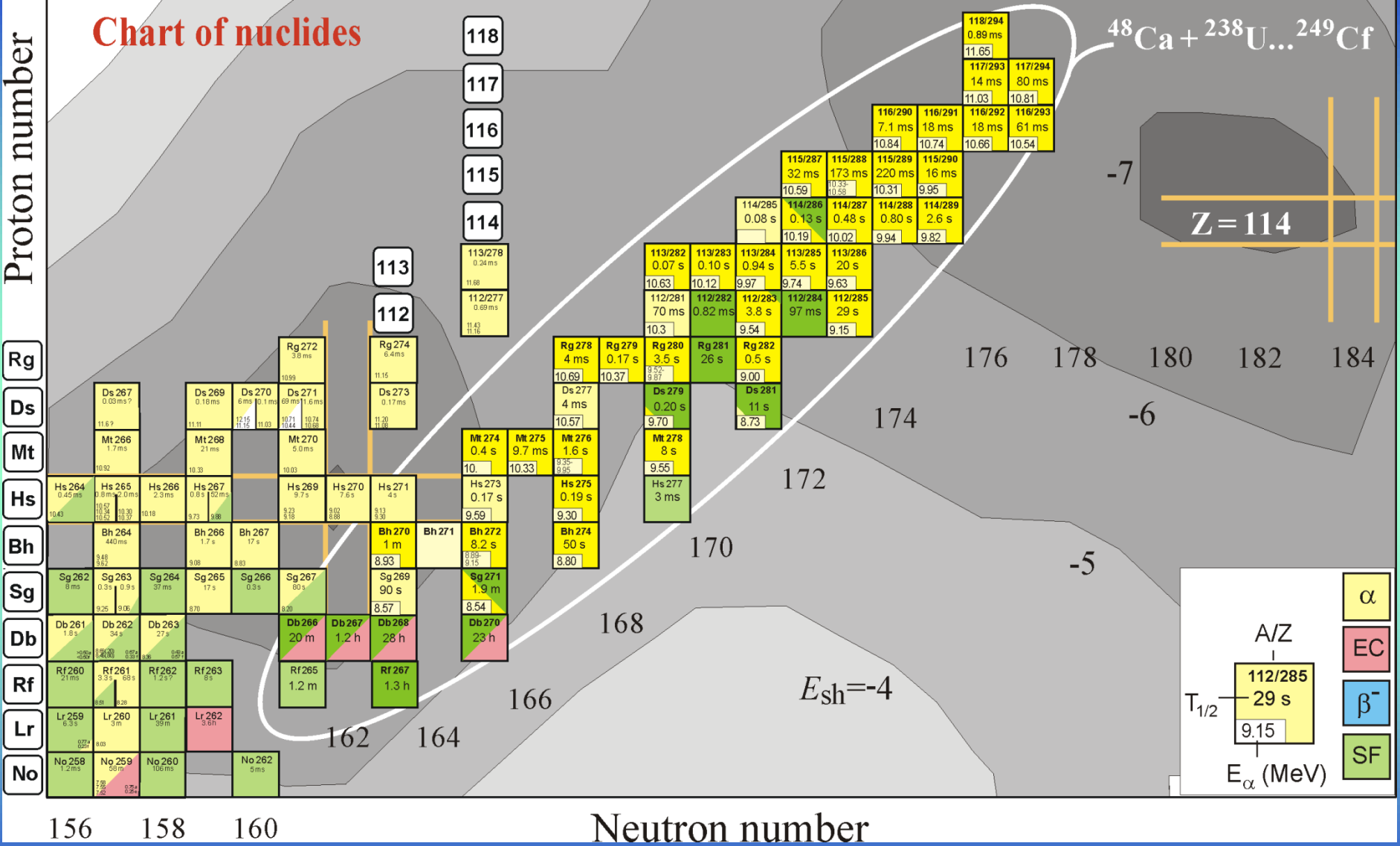
Cross section (pb)



$^{266-270}\text{Db}$   
SF/ $\beta$



# Proton number



## Neutron number

