Nuclear Alchemy—The Sorcery of Synthesizing New Chemical Elements

Exotic Beam Summer School

July 30, 2014

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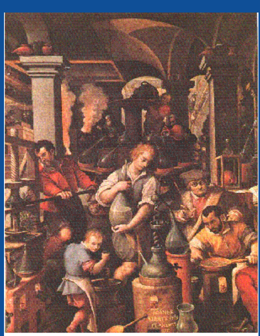
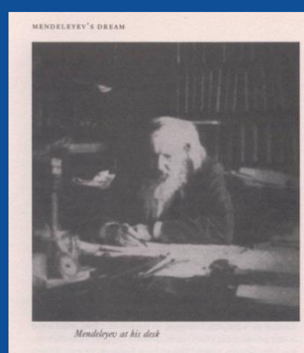




LLNL-PRES-657919

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

What is the definition of a chemical element?

A) A substance that cannot be separated by chemical processes into simpler substances

B) Atoms having the same number of electrons

C) Atoms having the same number of neutrons

D) Atoms having the same number of protons

Answer: A or D

How would you “discover” a new element?

A) Combine a bunch of chemicals in a test tube and chant special incantations while heating with a Bunsen burner

B) Chemically process tons of dirt/ore

C) Use a nuclear reaction

D) Look for spectral lines in the galaxy using x-ray and gamma-ray detectors

Answer: C but all have been tried

What nuclear reaction would you try to make element 118?

A) $^{86}Kr + ^{208}Pb \rightarrow 1n + ^{293}118$ — Was tried but cross-section << 1 fb!

B) $^{141}Pr + ^{141}Pr \rightarrow 2n + ^{280}118$ — Coulomb barrier and neutron deficiency work against

C) $^{4}He + ^{293}116 \rightarrow 3n + ^{294}118$ — Can't get target material

D) $^{48}Ca + ^{249}Cf \rightarrow 3n + ^{294}118$

Answer: D

Mendeleev’s 1869 periodic table enabled a quantum leap in chemical understanding

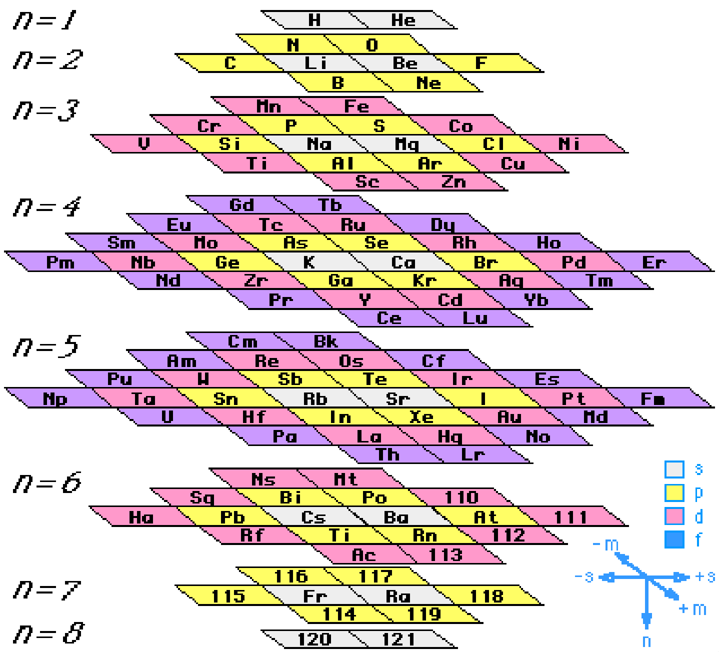
Mendeleev's Periodic Table (1869) http://140.198.18.108/periodic/foldedtable.htm

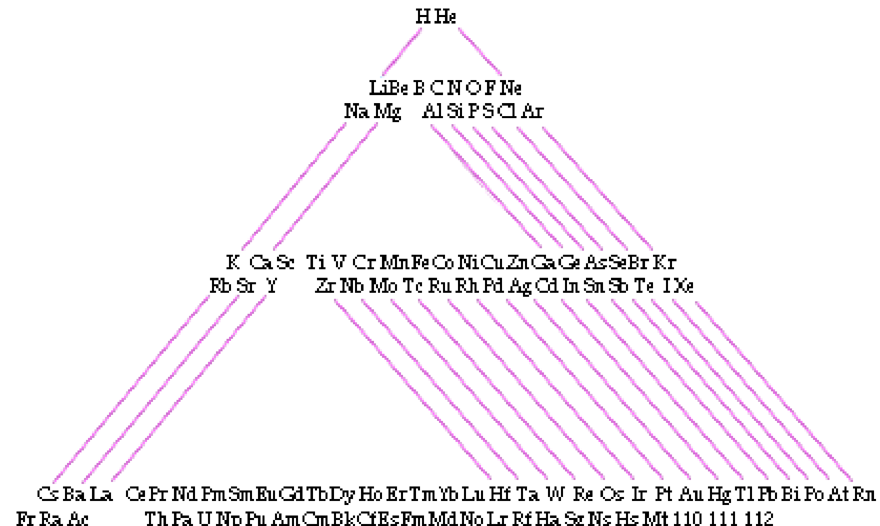
Dimitri Mendeleev created this, the original, periodic table.

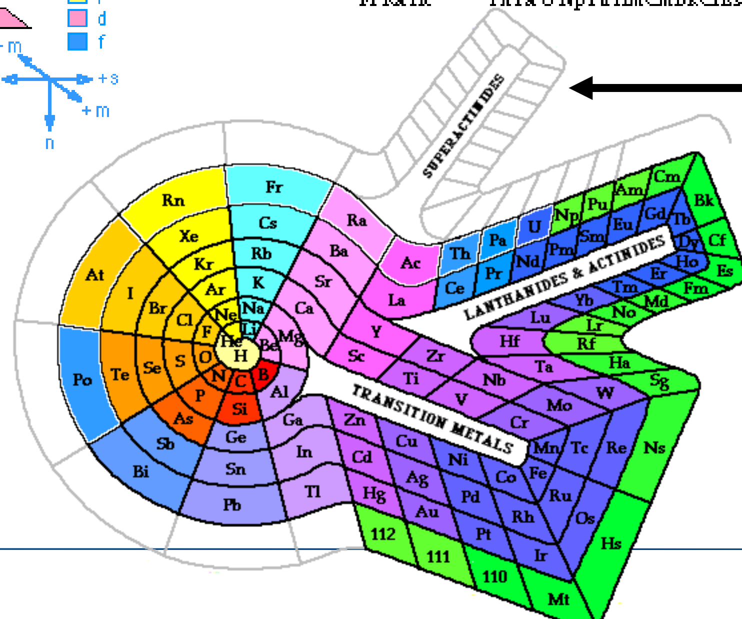
Reihen	Gruppe I. - R^2O	Gruppe II. - RO	Gruppe III. - R^2O^3	Gruppe IV. RH^4 RO^2	Gruppe V. RH^3 R^2O^5	Gruppe VI. RH^2 RO^3	Gruppe VII. RH R^2O^7	Gruppe VIII. - RO^4
1	H = 1							
2	Li = 7	Be = 9,4	B = 11	C = 12	N = 14	O = 16	F = 19	
3	Na = 23	Mg = 24	Al = 27,3	Si = 28	P = 31	S = 32	Cl = 35,5	
4	K = 39	Ca = 40	- = 44	Ti = 48	V = 51	Cr = 52	Mn = 55	Fe = 56, Co=59 Ni=59, Cu=63
5	(Cu = 63)	Zn = 65	- = 68	- = 72	As = 75	Se = 78	Br = 80	
6	Rb = 85	Sr = 87	?Yt = 88	Zr = 90	Nb = 94	Mo = 96	- = 100	Ru=104, Rh=104 Pd=106, Ag=108
7	Ag = 108	Cd = 112	In = 113	Sn = 118	Sb = 122	Te = 125	J = 127	
8	Cs = 133	Ba = 137	?Di = 138	?Ce = 140	-	-	-	- - - -
9	(-)	-	-	-	-	-	-	
10	-	-	?Er = 178	?La = 180	Ta = 182	W = 184	-	Os=195, Ir=197, Pt=198, Au=199
11	(Au = 199)	Hg = 200	Tl = 204	Pb = 207	Bi = 208	-	-	
12	-	-	-	Th = 231	-	U = 240	-	- - - -

Mendeleyev used this new tool to predict the existence of chemical elements that hadn't been discovered yet; they were found several years later

Now there are a variety of ways to visualize chemical periodicity

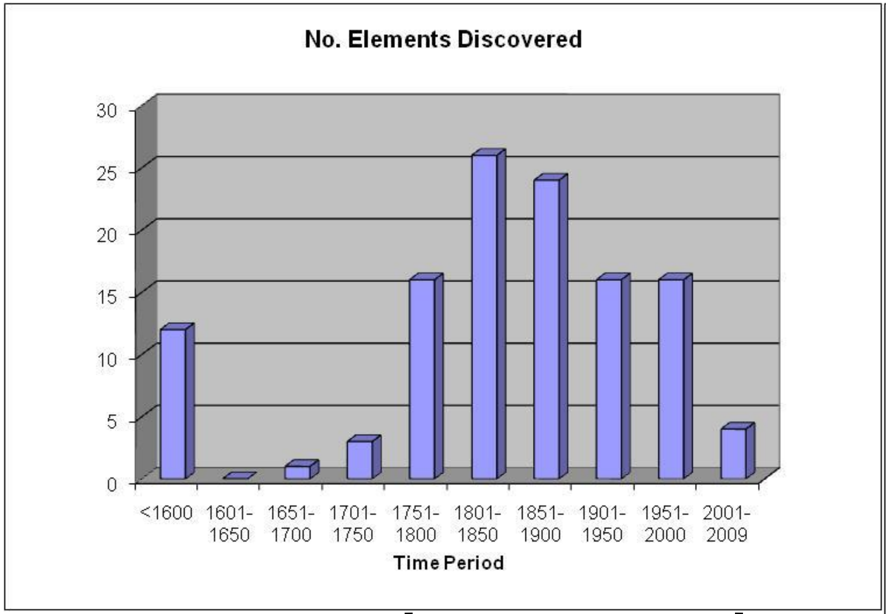


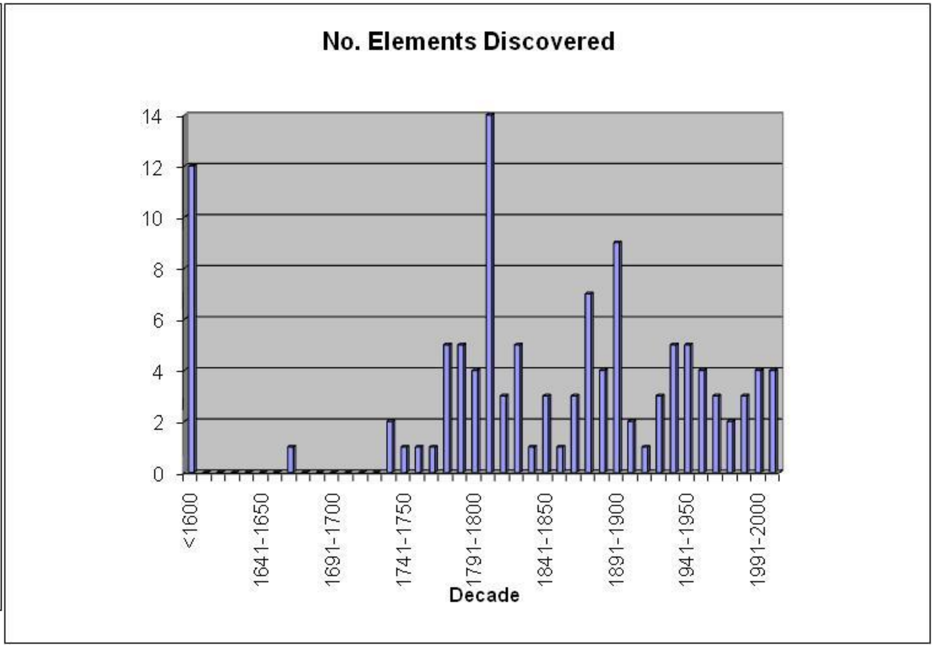




g-orbitals are predicted to start filling at Z=120!

New element discovery has progressed steadily since the 1700's





On average, just under 20 elements have been discovered every half-century

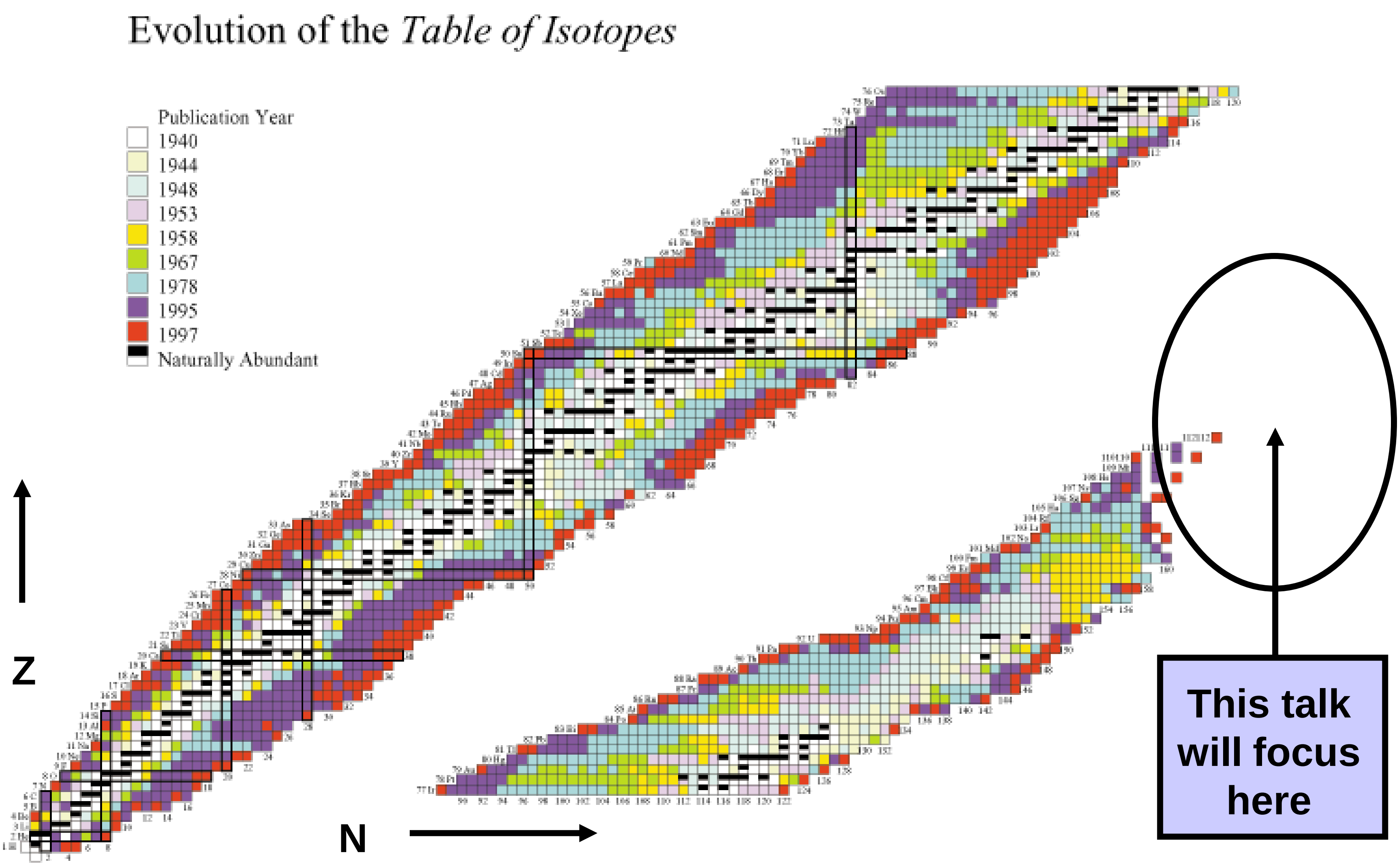
On average, about 4 elements have been discovered every decade

Laboratories have tended to discover a series of consecutive elements in recent history (1940 – 2010)

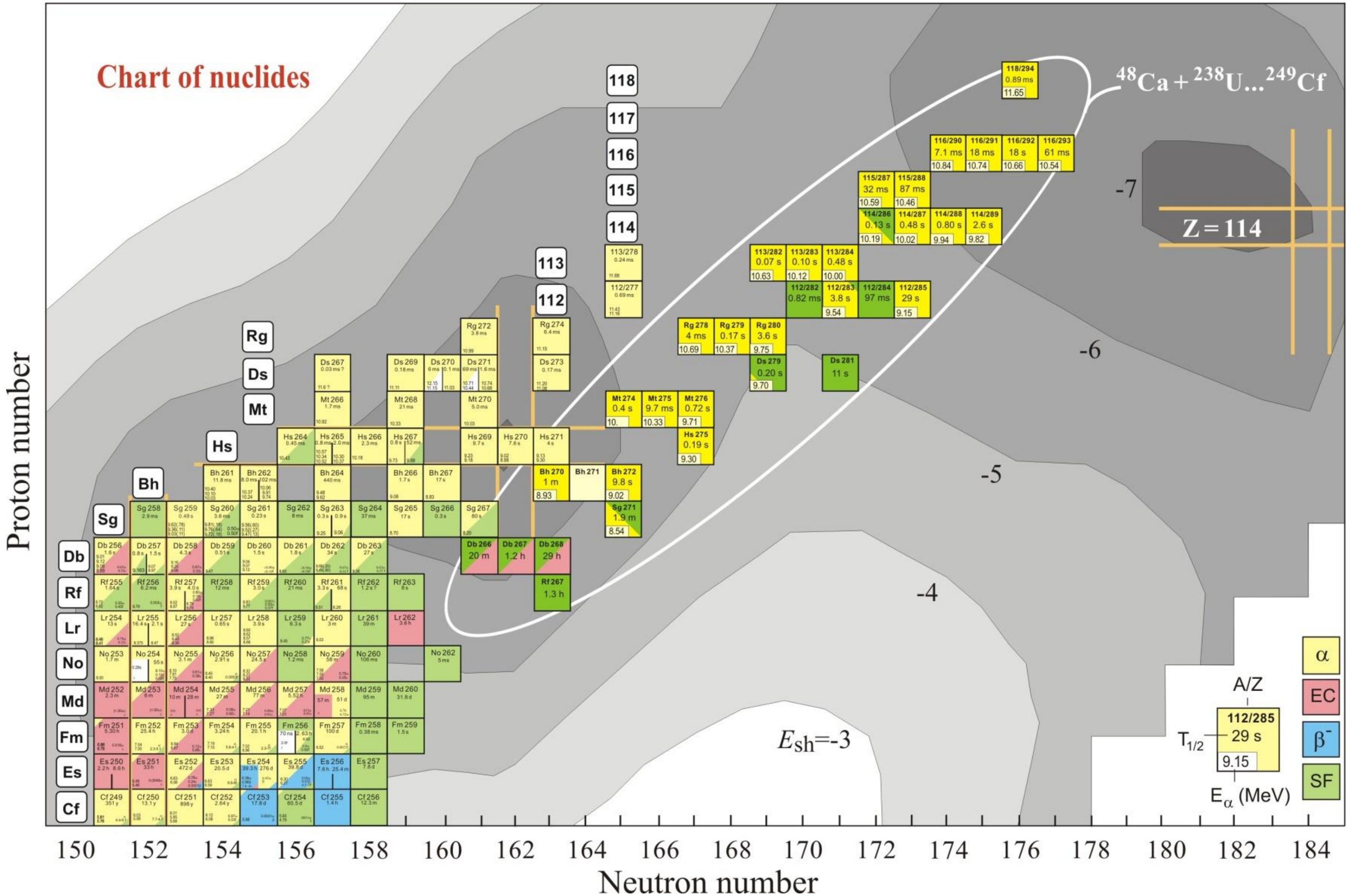
- LBL discovered elements 93, 94, 95, 96, 97, 98, 101, 103, 104, 105, 106
- Argonne/LANL discovered elements 99 and 100
- GSI discovered elements 107, 108, 109, 110, 111, 112
- Dubna/LLNL now finding evidence for elements 113, 114, 115, 116, 117 and 118
- Names for element 114 (flerovium, Fl) and 116 (livermorium, Lv)

The work described in this talk requires confirmation, preferably by another experimental group, before discovery can be claimed

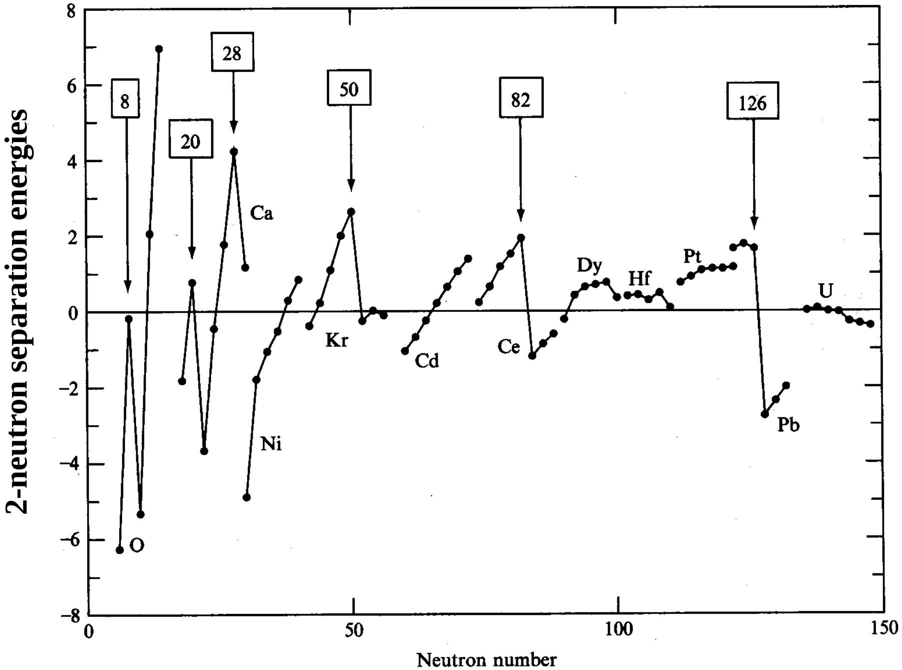
New isotope discovery has been rapid since the mid-1900's and routinely operating particle accelerators

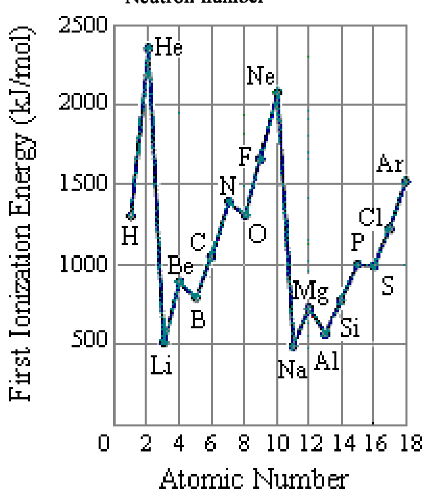


Upper end of the chart of nuclides in 2008



The existence of certain "magic" numbers of neutrons or protons has been known for nuclei, prompting the development of the shell model and analogies to filled electronic orbits in chemistry





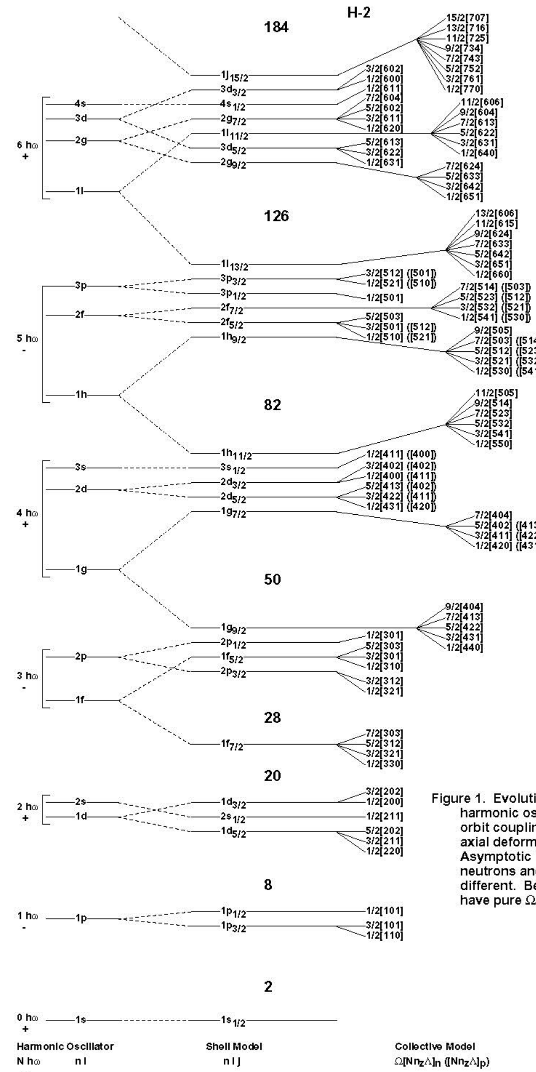


Figure 1. Evolution of nuclear models from the harmonic oscillator model, adding strong spin-orbit coupling to obtain the shell model, and axial deformation to give the collective model. Asymptotic Nilsson configurations are given for neutrons and, in parentheses, for protons when different. Because of mixing, very few states have pure $\Omega[Nn_z\Lambda]$ configurations.

Are “magic” numbers universal throughout the chart of nuclides?

A) Yes – they are 2, 8, 20, 28, 50, 82, 126, 184 …

B) No – Because of the complex interactions between nucleons in the nucleus, they change with different ratios of protons/neutron

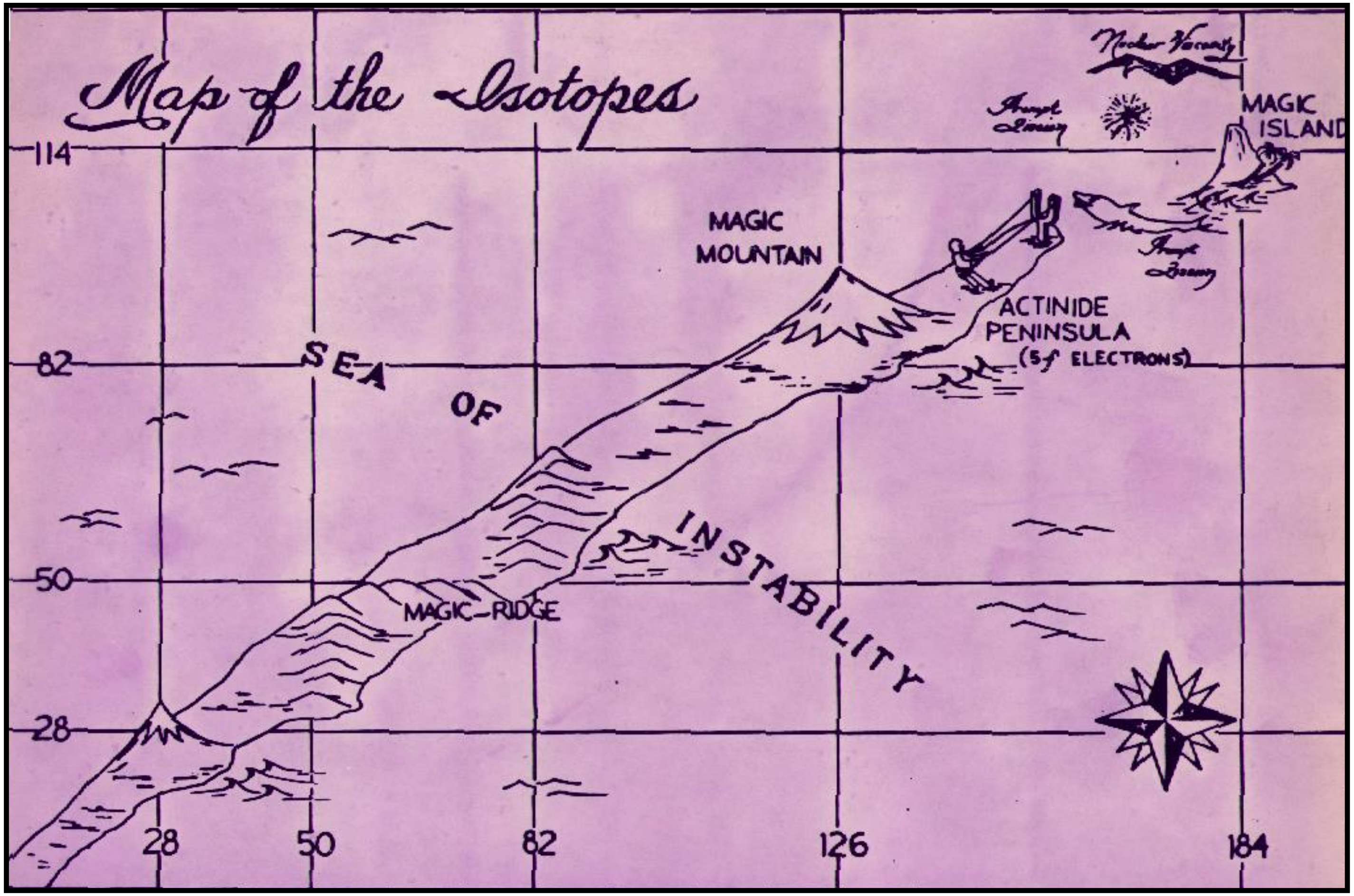
Answer: B

Scientists tried unsuccessfully for 40 years to find the "Island of Stability"

- One of the first predictions of the nuclear shell model was that the next doubly-magic spherical nucleus after ^{208}Pb lay at Z=126 and N=184.
- In the mid-60's, refined predictions indicated that the peak of the "Island of Stability" was at Z=114. This put a superheavy compound nucleus much more within reach of heavy-ion accelerator capability.
- Early half-life estimates varied from picoseconds to gigayears, the latter prompting searches in nature.
- Both chemical and physical methods have been tried.
- Attempts using exotic projectile/target isotopes have been as unsuccessful as those involving readily available materials.

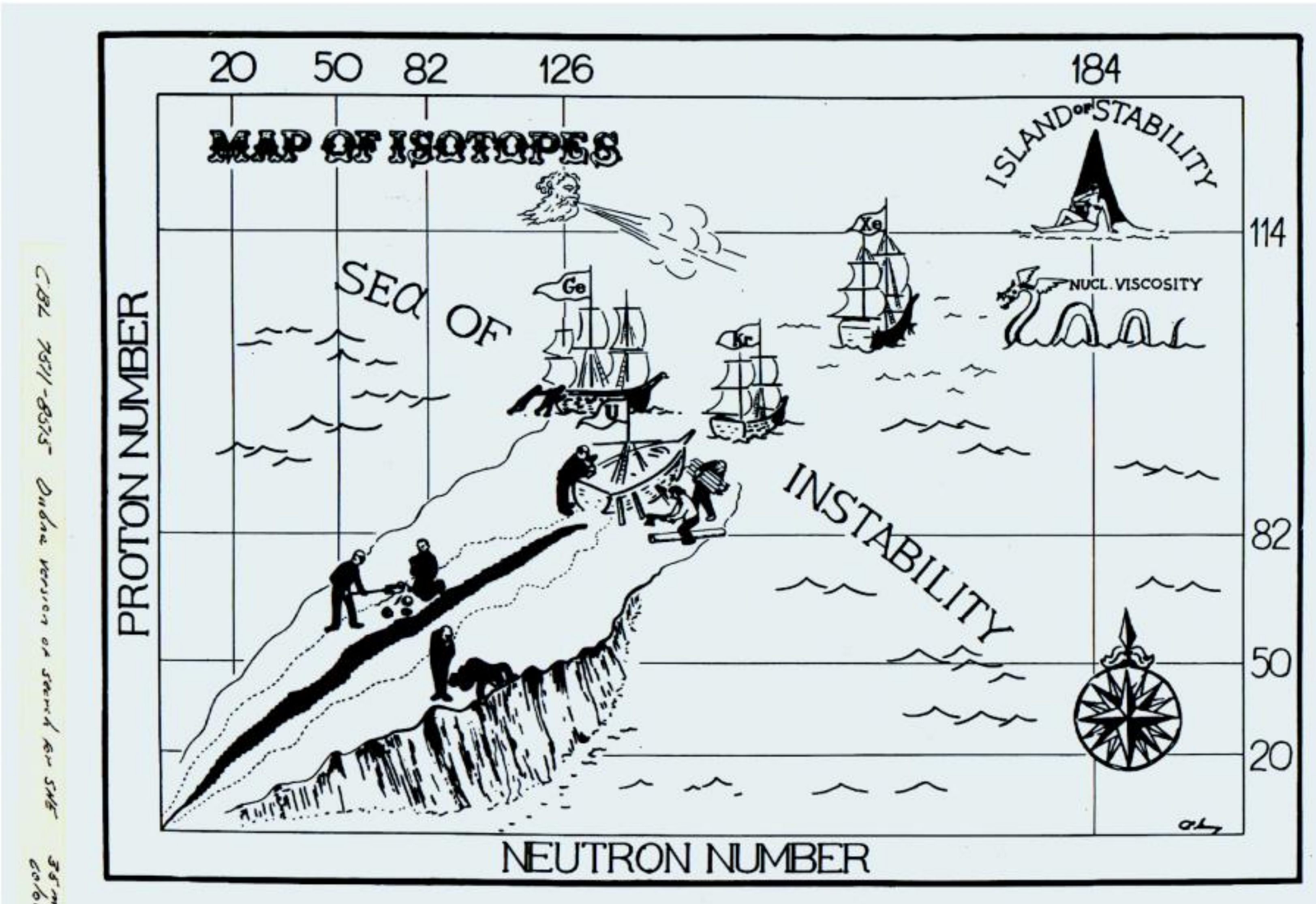
Nuclear theory at Berkeley, circa 1969

Proton number



Neutron number

Nuclear theory in the Soviet Union, circa 1969



Modern nuclear theory has done a much better job at modeling superheavy nuclei (and suspect with this new data models will improve)

- **Computer capabilities are many orders of magnitude greater now than they were 30 years ago.**
- **Extrapolations to superheavy element properties from those of known nuclei are much shorter than those of 30 years ago.**
- **Predictions of significantly enhanced nuclear stability at Z=114 extend down to neutron numbers as low as N=175.**
- **Predicted half lives are seconds to minutes.**
- **Production cross sections are extremely low, even for the most optimal reactions.**

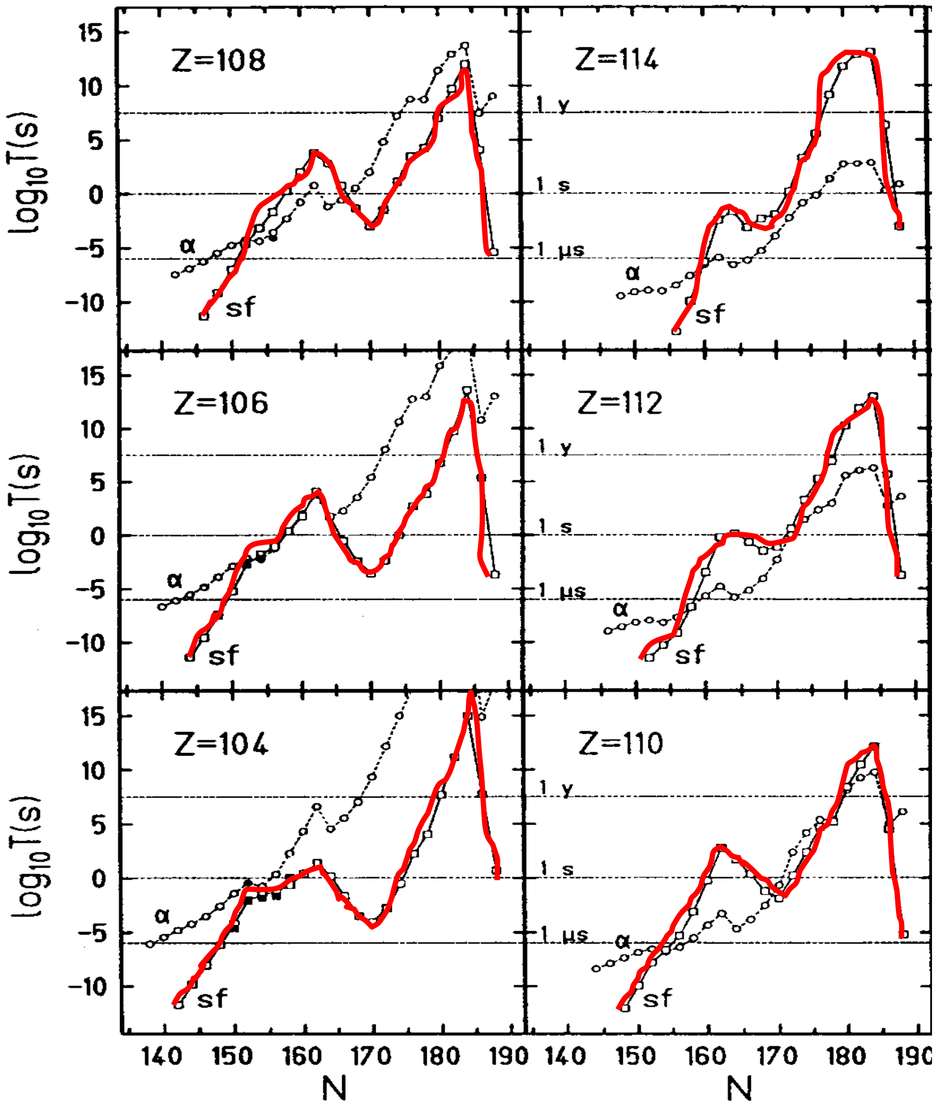
(Latest calculations are a bit more ambiguous about the location of the closed proton shell, some models indicate Z=114, Z=120 or even Z=126—all indicate N=184)

The results of the predictions enabled us to plan experiments in this region

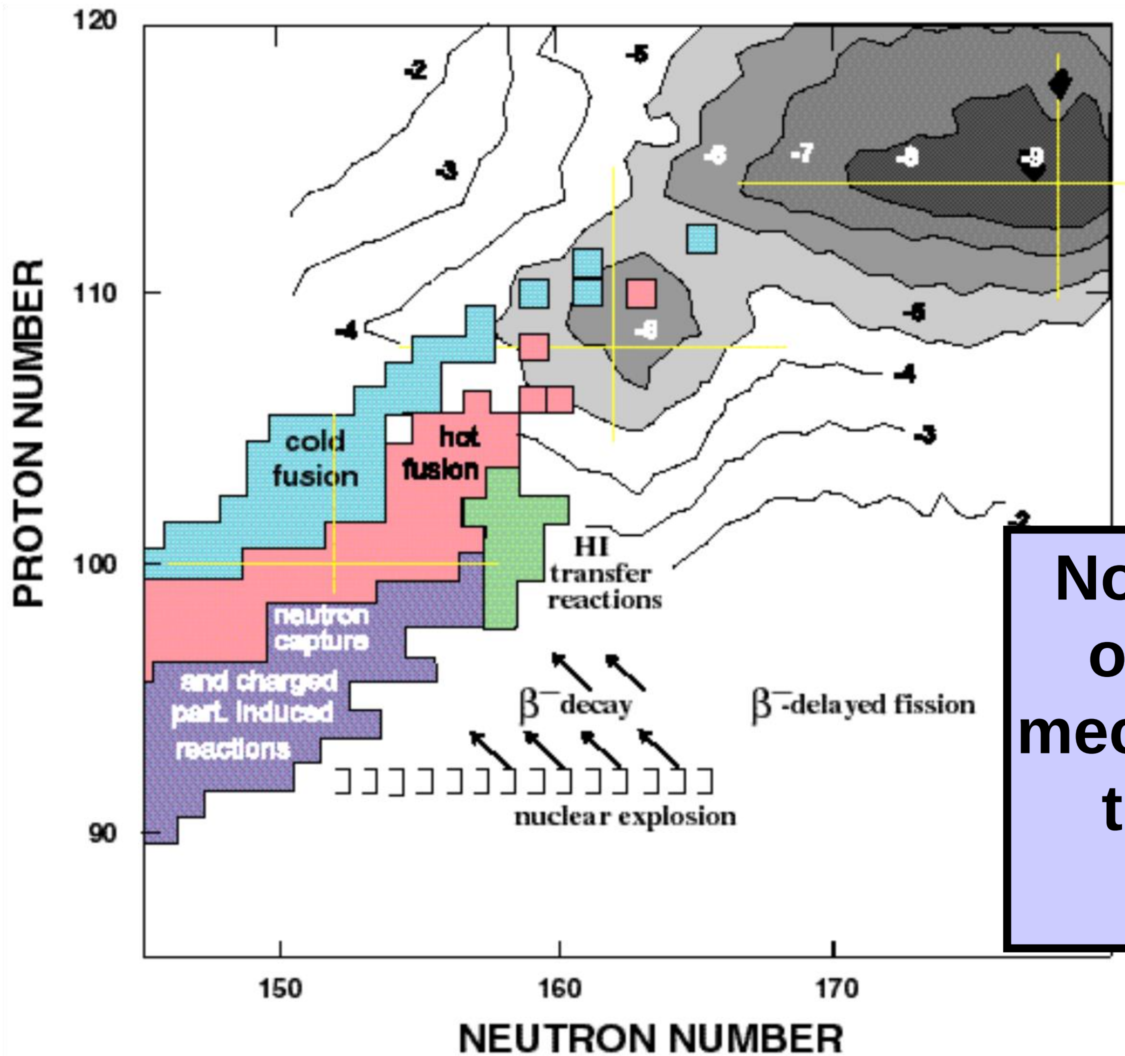
- **With increasing nuclear charge, decay by alpha-emission becomes favored over decay by SF as one approaches the vicinity of the closed nuclear shells**

- **The signature of the decay of a superheavy nucleus is a series of alpha decays followed by a spontaneous fission**

- **The reaction of ^{48}Ca with ^{244}Pu results in a compound nucleus with Z=114 and N=178**



The heaviest known nuclei (ca 1998), superimposed on the calculated shell corrections to the liquid drop model



Note the variety of production mechanisms used to make new elements!

Typical techniques for producing Heavy Elements or SHE

- **Most facilities use heavy ion accelerators to bombard targets and produce fusion/evaporation residues for further study, although transfer reactions are sometimes possible**
  - "Cold Fusion" reactions (e.g. ^{70}Zn + ^{208}Pb)
  - "Hot Fusion" reactions (e.g. ^{48}Ca + ^{243}Am)
- **Separation of "Goodies" from unwanted products**
  - Separators like DGFS, BGS
  - Separators like VASSALISSA, SHIP
  - Advanced separators (MASHA …)
  - Fast and/or automated chemistry
- **Detection and identification of "Goodies"**

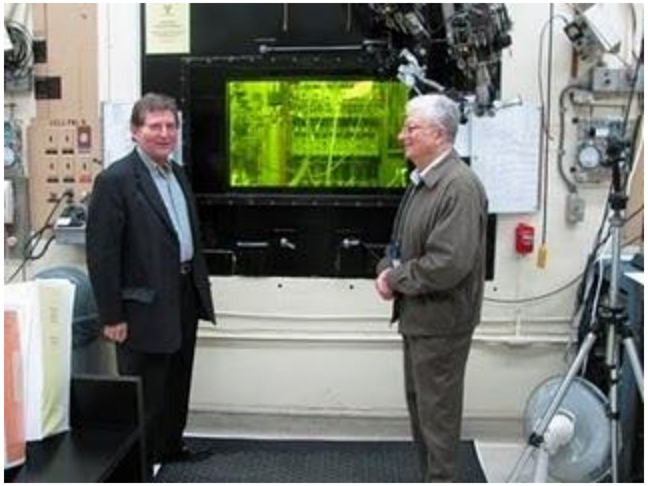
Experimental details of the 117 experiment

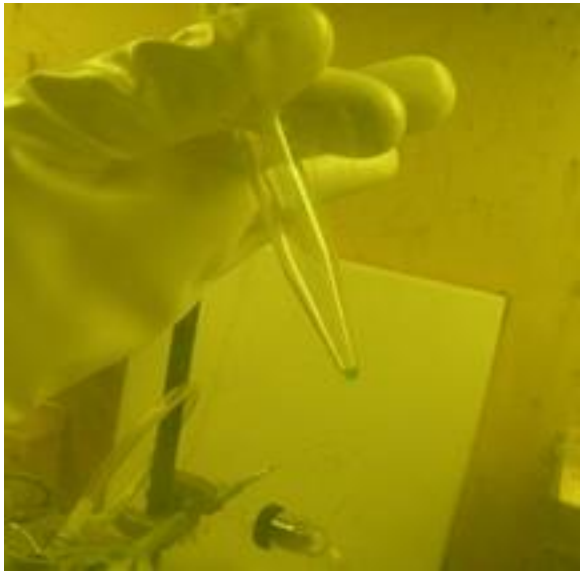
- Experiment performed at U400 cyclotron in Dubna, Russia (JINR)
- Beam was ^{48}Ca – a rare isotope of Ca and the most neutron-rich (note that this nucleus is doubly magic—Z=20 and N=28)
- Target was ^{249}Bk electroplated on a wheel – total of ~15 mg (note that this corresponds to 25 Ci of activity) [Note $t_{1/2}$ = 320 d!!!!]
- Beam time was between 7/27/09 and 2/25/10—a total of ~150 days
- 2.4×10^{19} particles delivered at beam energy of 252 MeV and 2×10^{19} particles delivered at beam energy of 247 MeV (note that the total number of delivered ^{48}Ca ions was 4.5×10^{19} or 3.6 mg) – Beam was switched off when an interesting EVR-α event was recorded
- The Dubna gas-filled separator was used to reduce the unused beam, transfer reaction products, and other background—the separator had an efficiency of ~35-40%
- Evaporation residues were implanted in a detector and decay events were detected—the detector system had an efficiency of ~87%
- The predicted cross-section was ~ 1 pb

We observed 6 events consisting of position correlated EVR implants, alpha-decays, and terminated by SF

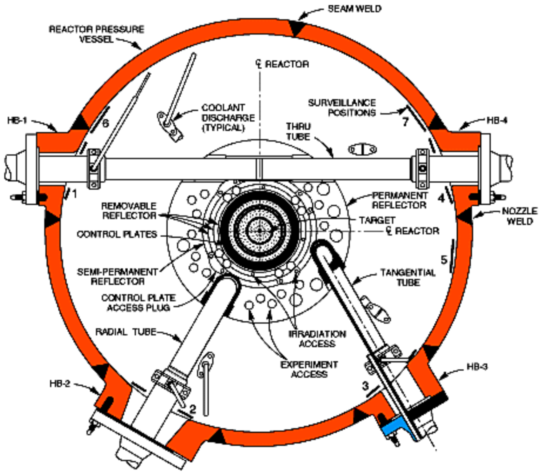
Target material was fabricated at ORNL HFIR

- 22.2 mg ^{249}Bk (36 Ci) was produced by irradiating Cm/Am for 250 days in highest flux reactor as a by-product of ^{252}Cf production
- Neutron flux was ~ 4×10^{15} n/cm^2/s
- After purification, less than 1.7 nCi ^{252}Cf remained in sample

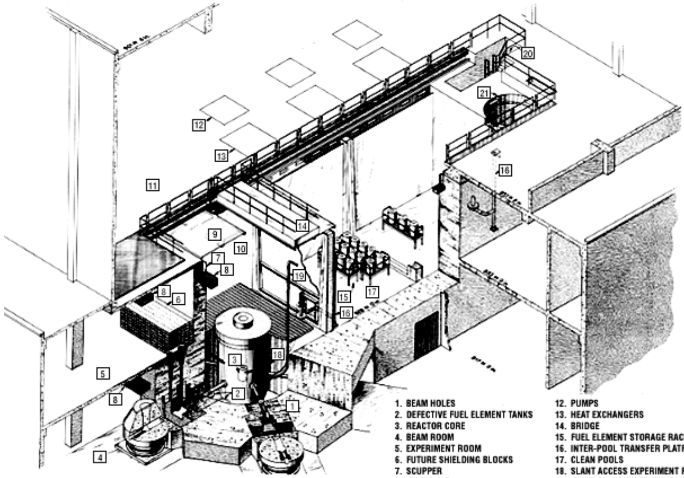




Oak Ridge High Flux Isotope Reactor

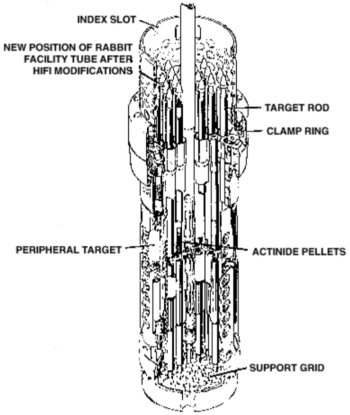


Sectional plan view of reactor core



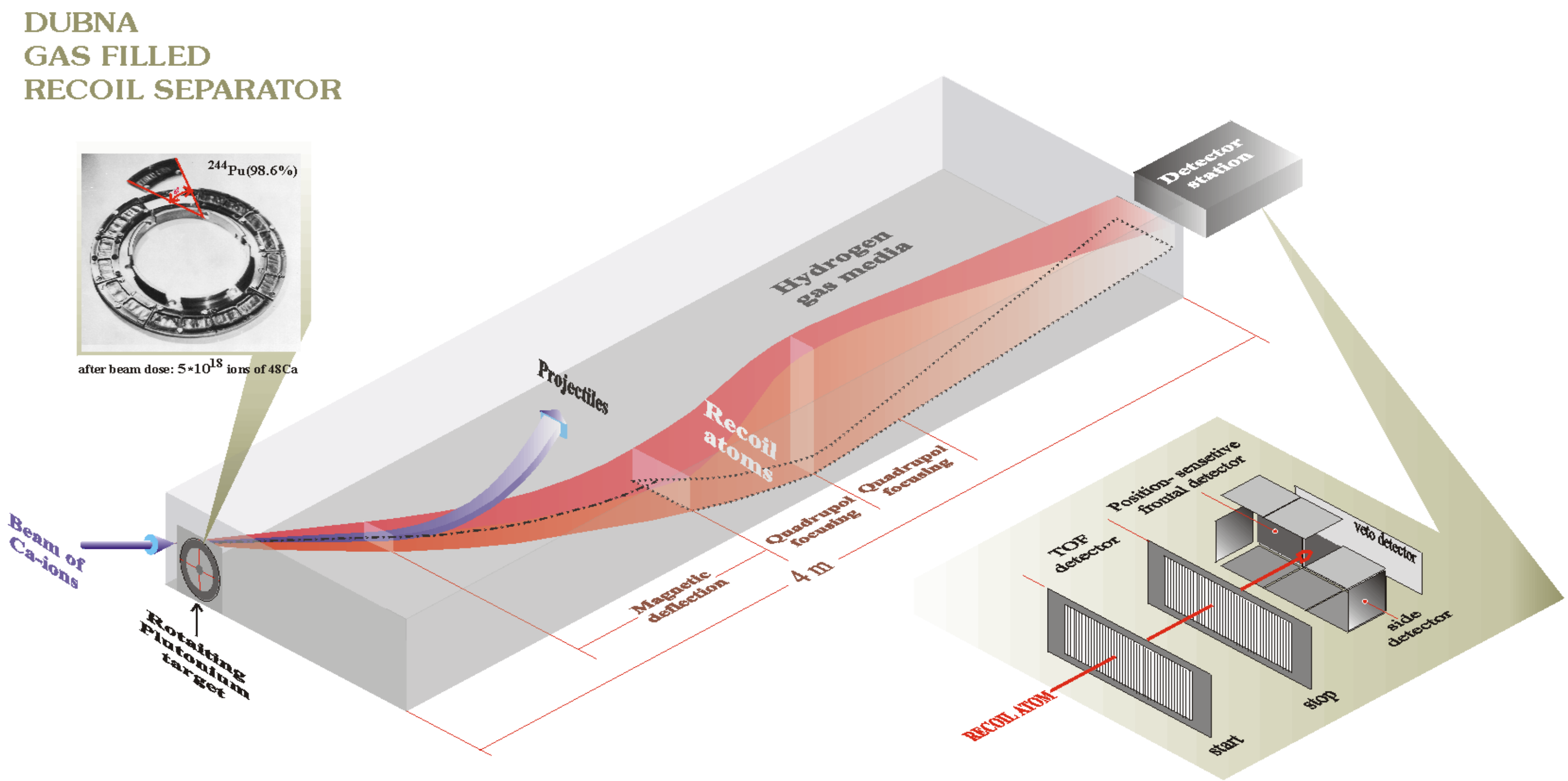
1. BEAM HOLES
2. DEFECTIVE FUEL ELEMENT TANKS
3. REACTOR CORE
4. BEAM ROOM
5. EXPERIMENT ROOM
6. FUTURE SHIELDING BLOCKS
7. SCUPPER
8. SBHE DUCT
9. POOL COVER
10. REACTOR POOL
11. REACTOR BAY
12. PUMPS
13. HEAT EXCHANGERS
14. BRIDGE
15. FUEL ELEMENT STORAGE RACKS
16. INTER-POOL TRANSFER PLATFORMS
17. CLEAN POOLS
18. SLANT ACCESS EXPERIMENT FACILITIES
19. NEUTRON-CHAMBER THINBLES
20. TOOL STORAGE PIT
21. PROVISION FOR CRITICAL FACILITY

Pools and experiment facilities



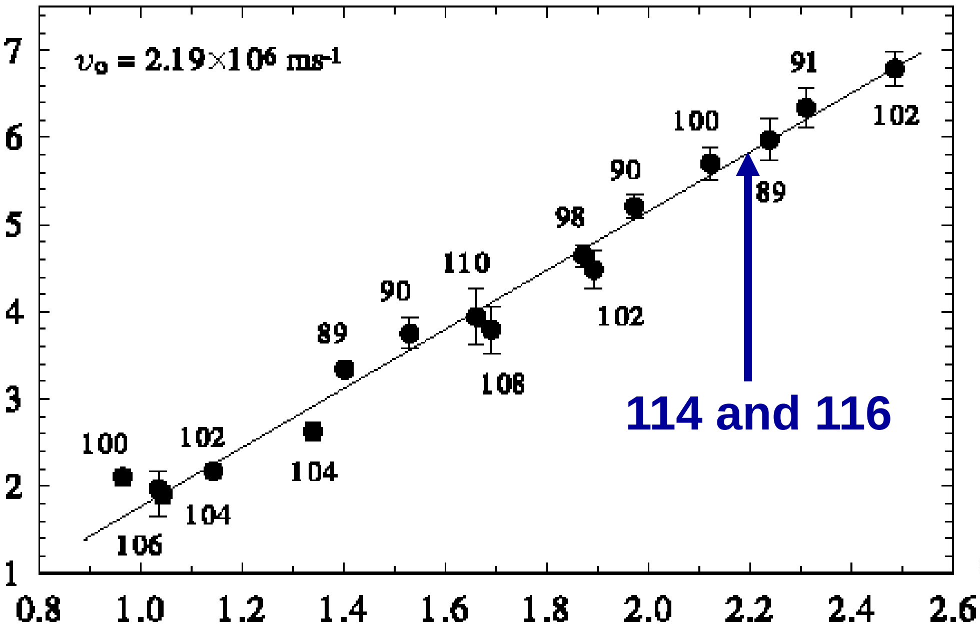
TARGET HOLDER ASSEMBLY

The Dubna gas-filled separator uses a combination of chemistry and physics to suppress unwanted reaction products

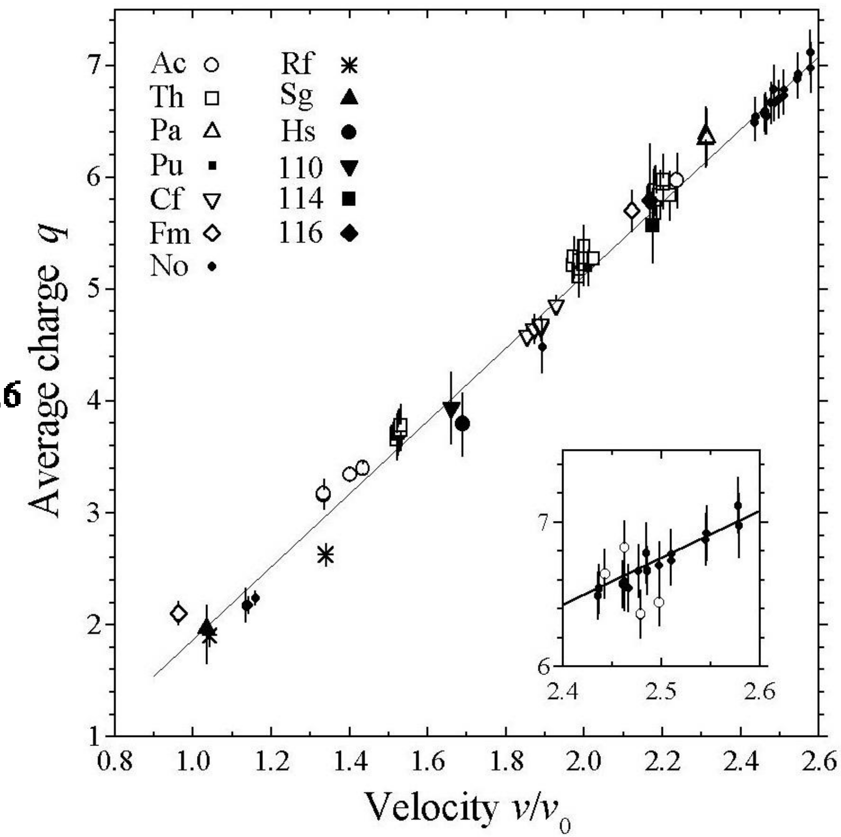


Yuri Oganessian FLNR (JINR) June 14, 1999

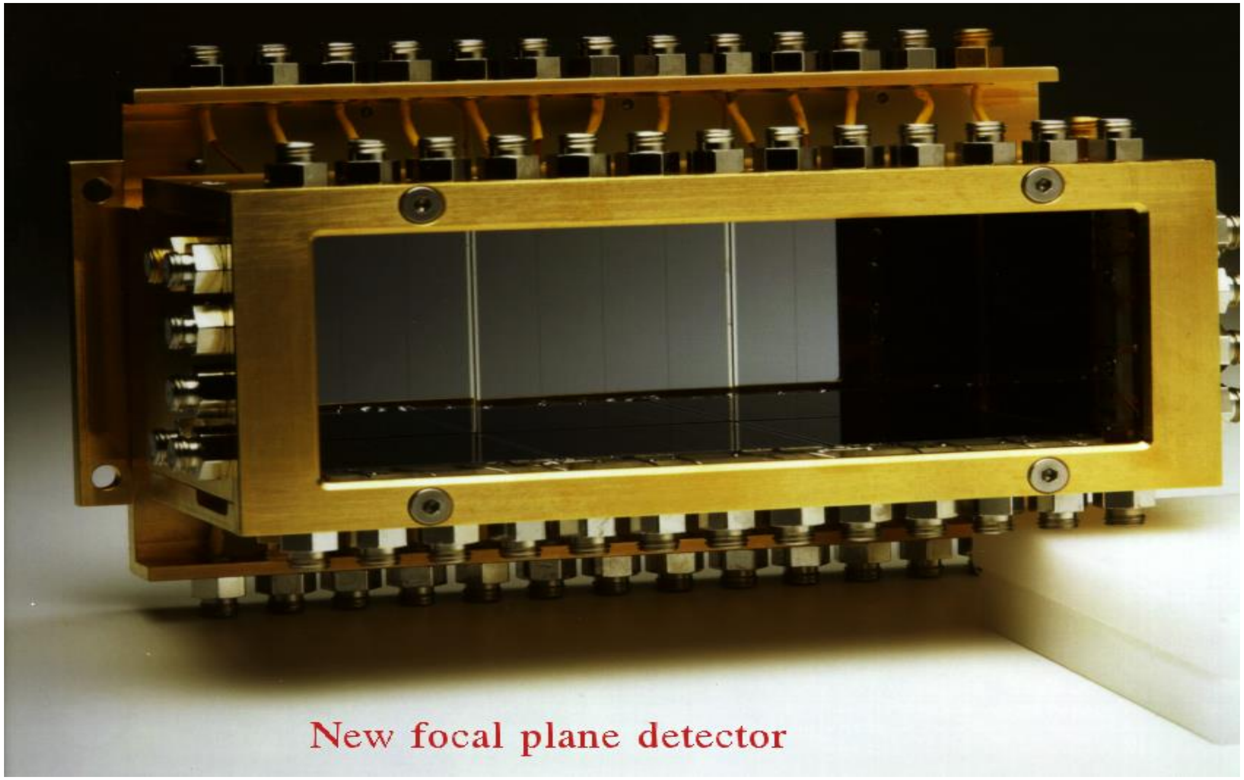
Average charge state measurements of evaporation residues in hydrogen define the separator dipole current for these experiments



An interesting interplay between chemistry and physics!



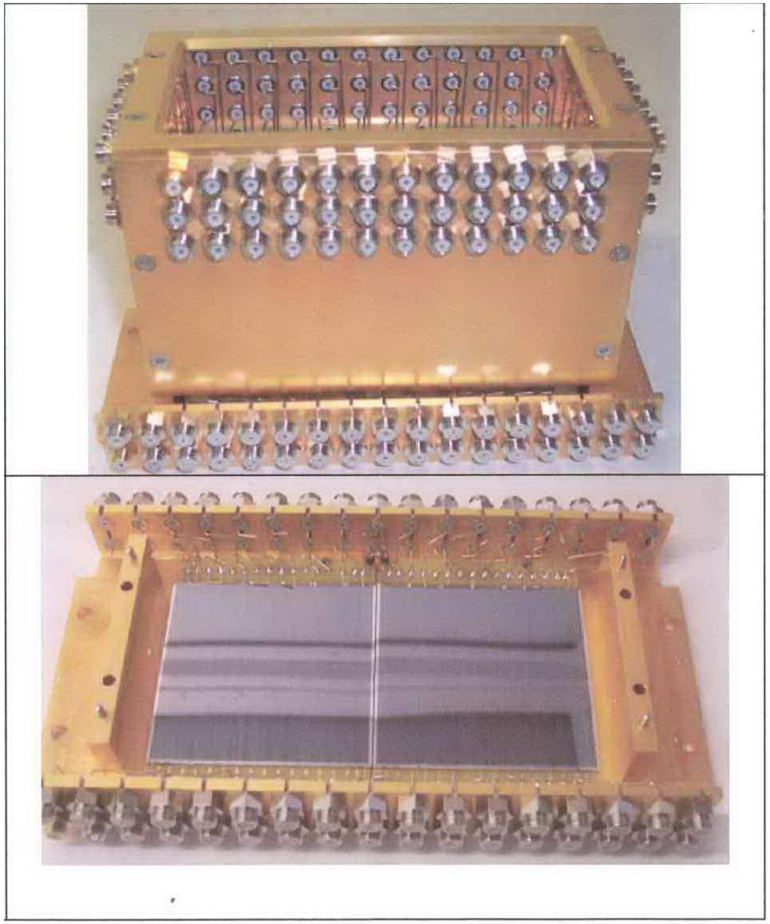
The high-efficiency detector system

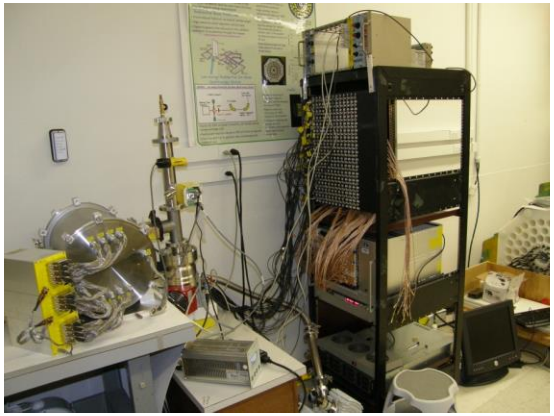


The addition of the top, bottom, and side detectors increased the geometry for counting α particles from 50% to 87%.

Veto detectors mounted behind the focal plane were used to identify and reject light charged particles passing through the separator.

A new detector has been installed at the DGFRS focal plane

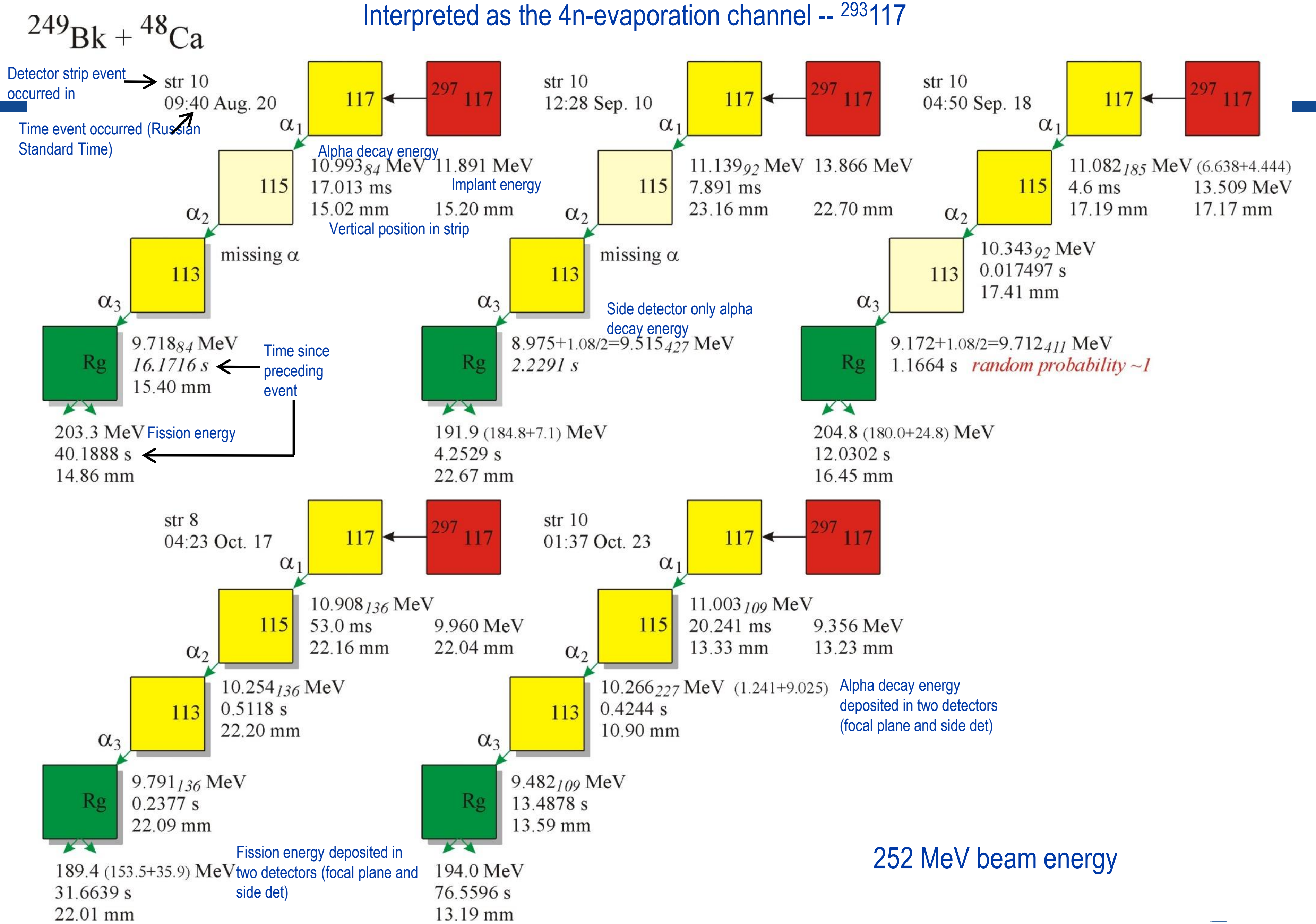




New digital electronics being tested at HRIBF and to be implemented soon in Dubna by ORNL

The new detector is comprised of 6 × 6 cm^2 16–strip Si DSSD detectors. Because the focal plane detector is larger the side detectors are also larger—the net result is that the detection efficiency is the same as the prior detector ~87%

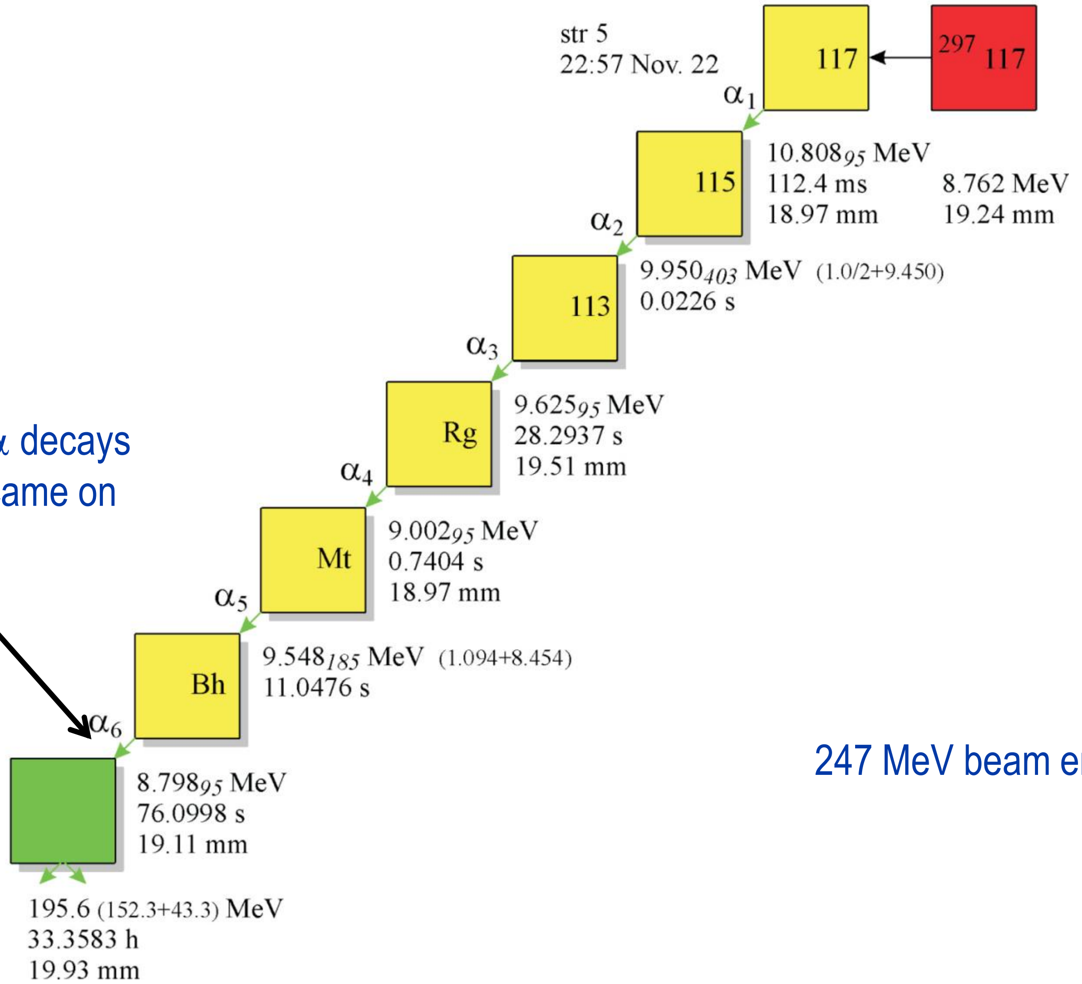
Interpreted as the 4n-evaporation channel -- $^{293}117$



252 MeV beam energy

Interpreted as the 3n-evaporation channel -- $^{294}117$

$^{249}Bk + ^{48}Ca$



May be missing α decays because beam came on

247 MeV beam energy

Decay properties of nuclides observed in element 117 experiments

TABLE II. Decay properties of nuclei produced in the reaction ^{249}Bk+^{48}Ca.

Isotope	Decay mode	Half-life[a]	E_α (MeV)	Q_α (MeV)	Isotope	Decay mode	Half-life[a]	E_α (MeV)	Q_α (MeV)
^{293}117	α	14^{+11}_{-4} ms (8 ms)	11.03±0.08	11.18±0.08	^{294}117	α	78^{+370}_{-36} ms (30 ms)	10.81±0.10	10.96±0.10
^{289}115	α	220^{+260}_{-80} ms (160 ms)	10.31±0.09	10.45±0.09	^{290}115	α	16^{+75}_{-8} ms (1.7 s)	9.95±0.40	10.09±0.40
^{285}113	α	$5.5^{+5.0}_{-3.7}$ s (1.7 s)	9.74±0.08 9.48±0.11	9.88±0.08	^{286}113	α	20^{+94}_{-9} s (4 s)	9.63±0.10	9.76±0.10
^{281}Rg	SF	26^{+25}_{-8} s	–	<9.4	^{282}Rg	α	$0.51^{+2.5}_{-0.23}$ s (70 s)	9.00±0.10	9.13±0.10
					^{278}Mt	α	$7.7^{+37.}_{-3.5}$ s (0.3 s)	9.55±0.19	9.69±0.19
					^{274}Bh	α	53^{+250}_{-24} s (14 s)	8.80±0.08	8.93±0.08
			–		^{270}Db	SF/α/ EC	23^{+110}_{-10} h	–	<7.9

[a] Error bars correspond to 68% confidence level. Expected half-lives for allowed transitions shown in parenthesis were calculated using formula by Viola and Seaborg [??] and measured Q_α values.

Alpha particle spectrum for element 117 experiment

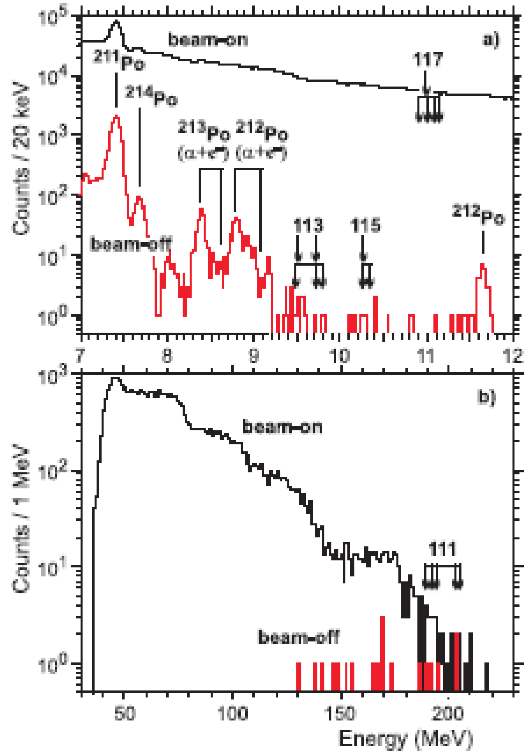


FIG. 2: Energy spectra recorded during the 252 MeV $^{48}Ca+^{249}Bk$ run (E^*=39 MeV). a) Total energy spectra of beam-on α-like signals and beam-off α-particles. b) Total fission-fragment energy spectra, both beam-on and beam-off. The arrows show the energies of events observed in the correlated decay chains, see Fig. 1.

Work is published in PRL (and NY Times)

Selected for a Viewpoint in *Physics*
PRL **104,** 142502 (2010) PHYSICAL REVIEW LETTERS week ending 9 APRIL 2010

Synthesis of a New Element with Atomic Number $Z = 117$

Yu. Ts. Oganessian,[1,*] F. Sh. Abdullin,[1] P. D. Bailey,[2] D. E. Benker,[2] M. E. Bennett,[3] S. N. Dmitriev,[1] J. G. Ezold,[2] J. H. Hamilton,[4] R. A. Henderson,[5] M. G. Itkis,[1] Yu. V. Lobanov,[1] A. N. Mezentsev,[1] K. J. Moody,[5] S. L. Nelson,[5] A. N. Polyakov,[1] C. E. Porter,[2] A. V. Ramayya,[4] F. D. Riley,[2] J. B. Roberto,[2] M. A. Ryabinin,[6] K. P. Rykaczewski,[2] R. N. Sagaidak,[1] D. A. Shaughnessy,[5] I. V. Shirokovsky,[1] M. A. Stoyer,[5] V. G. Subbotin,[1] R. Sudowe,[3] A. M. Sukhov,[1] Yu. S. Tsyganov,[1] V. K. Utyonkov,[1] A. A. Voinov,[1] G. K. Vostokin,[1] and P. A. Wilk[5]

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(Received 15 March 2010; published 9 April 2010)

The discovery of a new chemical element with atomic number $Z = 117$ is reported. The isotopes $^{293}117$ and $^{294}117$ were produced in fusion reactions between ^{48}Ca and ^{249}Bk. Decay chains involving 11 new nuclei were identified by means of the Dubna gas-filled recoil separator. The measured decay properties show a strong rise of stability for heavier isotopes with $Z \geq 111$, validating the concept of the long sought island of enhanced stability for superheavy nuclei.

DOI: 10.1103/PhysRevLett.104.142502 PACS numbers: 2

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Scientists Discover Heavy New Element

By JAMES GLANZ
Published: April 6, 2010

A team of Russian and American scientists has discovered a new element that has long stood as a missing link among the heaviest bits of atomic matter ever produced. The element, still nameless, appears to point the way toward a brew of still more massive elements with chemical properties no one can predict.

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Elusive Atoms

The team produced six atoms of the element by smashing together isotopes of calcium and a radioactive element called berkelium in a particle accelerator about 75 miles north of Moscow on the Volga River, according to a paper that has been accepted for publication at the journal Physical Review Letters.

Data collected by the team seem to support what theorists

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EDITORIAL

The Element Known As

Published: April 11, 2010

Left to nature, the element temporarily called "ununseptium" for its place on the periodic table of the elements — Latin, roughly, for "117-ness" — would never have materialized. But then along came a team of scientists working at the Dubna cyclotron, north of Moscow. According to a paper recently accepted for publication by the journal Physical Review Letters, they have been able to create six atoms of ununseptium by colliding isotopes of calcium (20 on the periodic table) and berkelium (97), which exists only in minute quantities.

Add the protons, which is what gives elements their atomic number, and you get 117, never mind how hard it is to do the addition in real life.

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Element 117 produced at GSI also

PRL 112, 172501 (2014) PHYSICAL REVIEW LETTERS week ending 2 MAY 2014

$^{48}Ca + ^{249}Bk$ Fusion Reaction Leading to Element $Z = 117$: Long-Lived α-Decaying ^{270}Db and Discovery of ^{266}Lr

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(Received 22 February 2014; published 1 May 2014)

The superheavy element with atomic number $Z = 117$ was produced as an evaporation residue in the $^{48}Ca + ^{249}Bk$ fusion reaction at the gas-filled recoil separator TASCA at GSI Darmstadt, Germany. The radioactive decay of evaporation residues and their α-decay products was studied using a detection setup that allowed measuring decays of single atomic nuclei with half-lives between sub-μs and a few days. Two decay chains comprising seven α decays and a spontaneous fission each were identified and are assigned to the isotope $^{294}117$ and its decay products. A hitherto unknown α-decay branch in ^{270}Db ($Z = 105$) was observed, which populated the new isotope ^{266}Lr ($Z = 103$). The identification of the long-lived ($T_{1/2} = 1.0^{+1.9}_{-0.4}$ h) α-emitter ^{270}Db marks an important step towards the observation of even more long-lived nuclei of superheavy elements located on an "island of stability."

DOI: 10.1103/PhysRevLett.112.172501 PACS numbers: 27.90.+b, 23.60.+e, 25.70.Gh

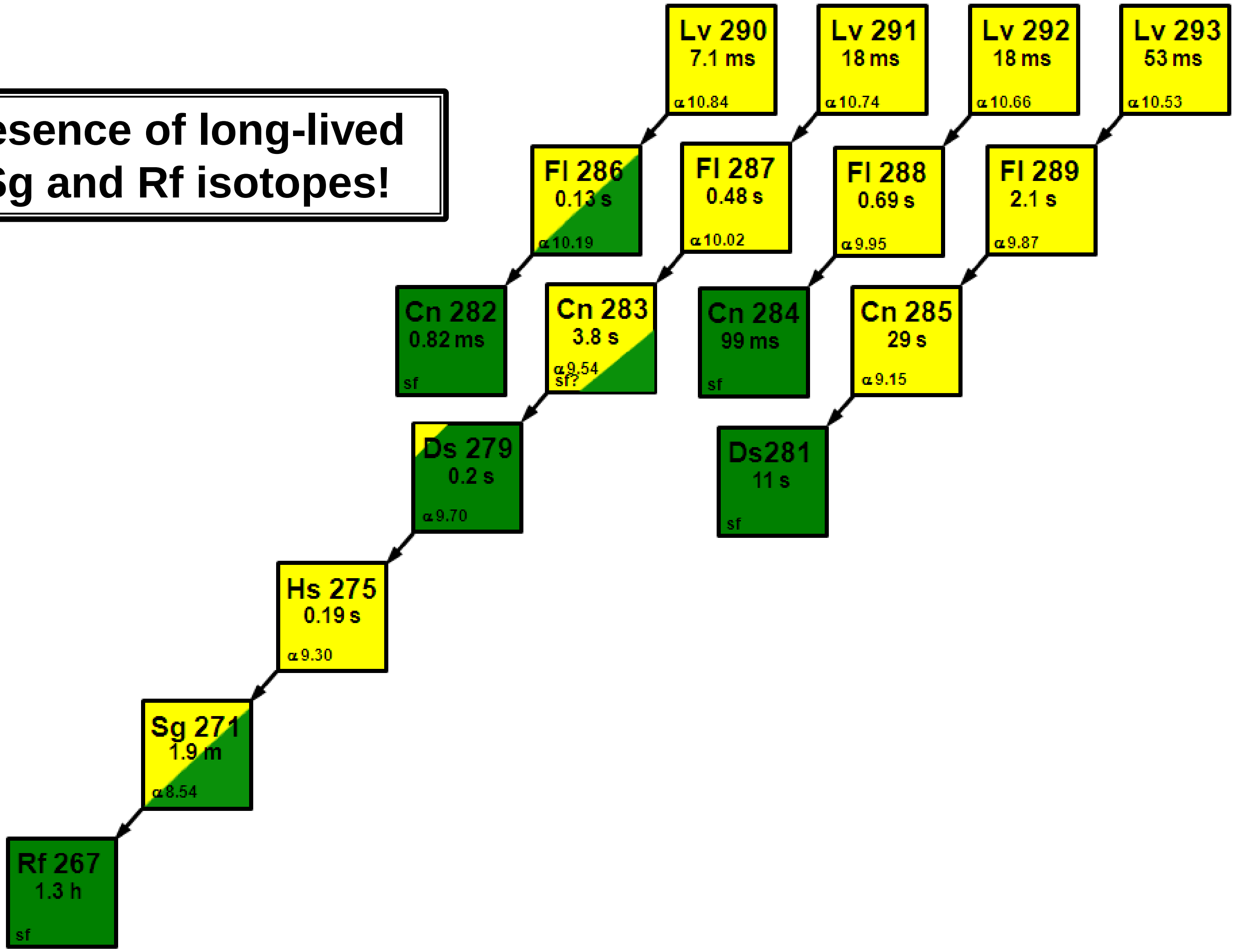
Lv video

We celebrated naming a new element Livermorium with the Mayors of Dubna and Livermore

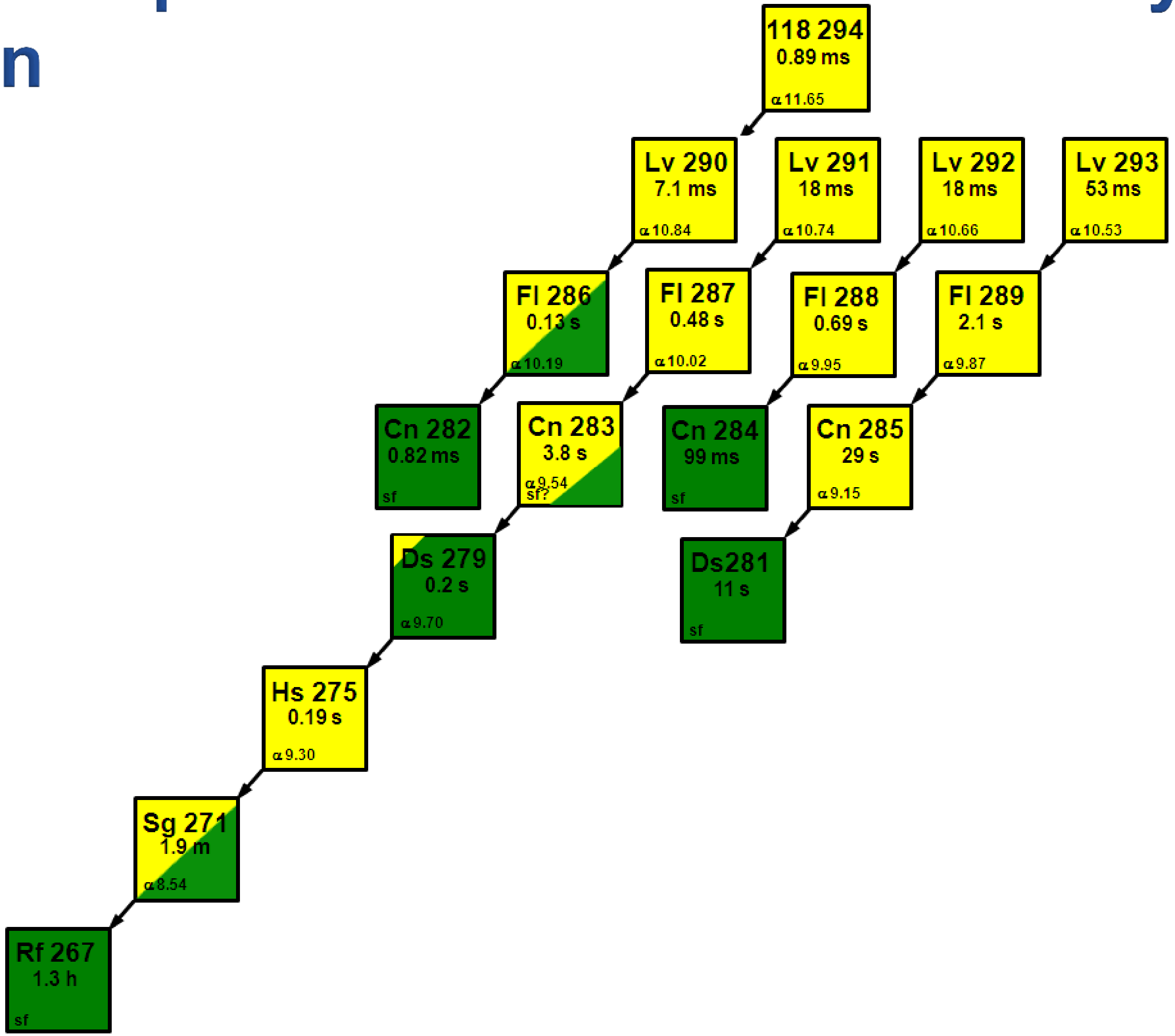
June 24, 2013 celebration

Lv currently has 4 isotopes with 10 – 50 ms half-lives – the odd-A chains are longer (due to hindrance)

Note the presence of long-lived Fl, Cn, Ds, Sg and Rf isotopes!



One isotope of element 118 is currently known



New data from the $^{48}Ca + ^{249}Bk$ reaction

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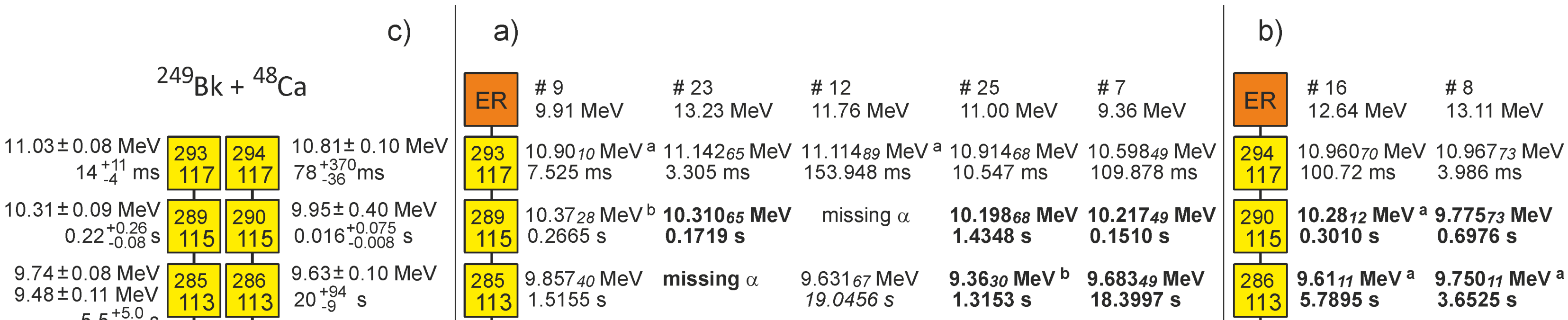
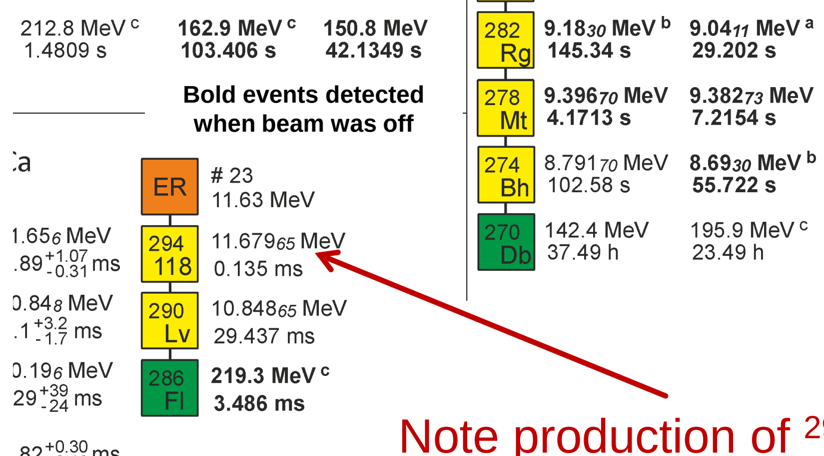
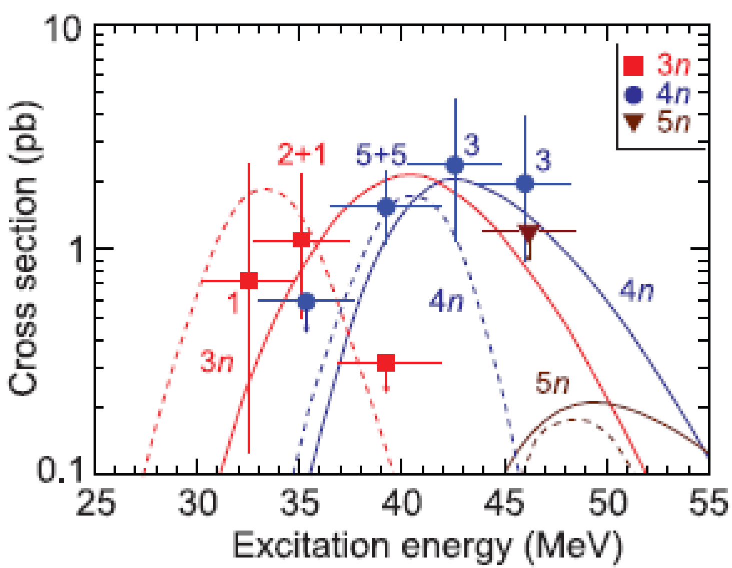




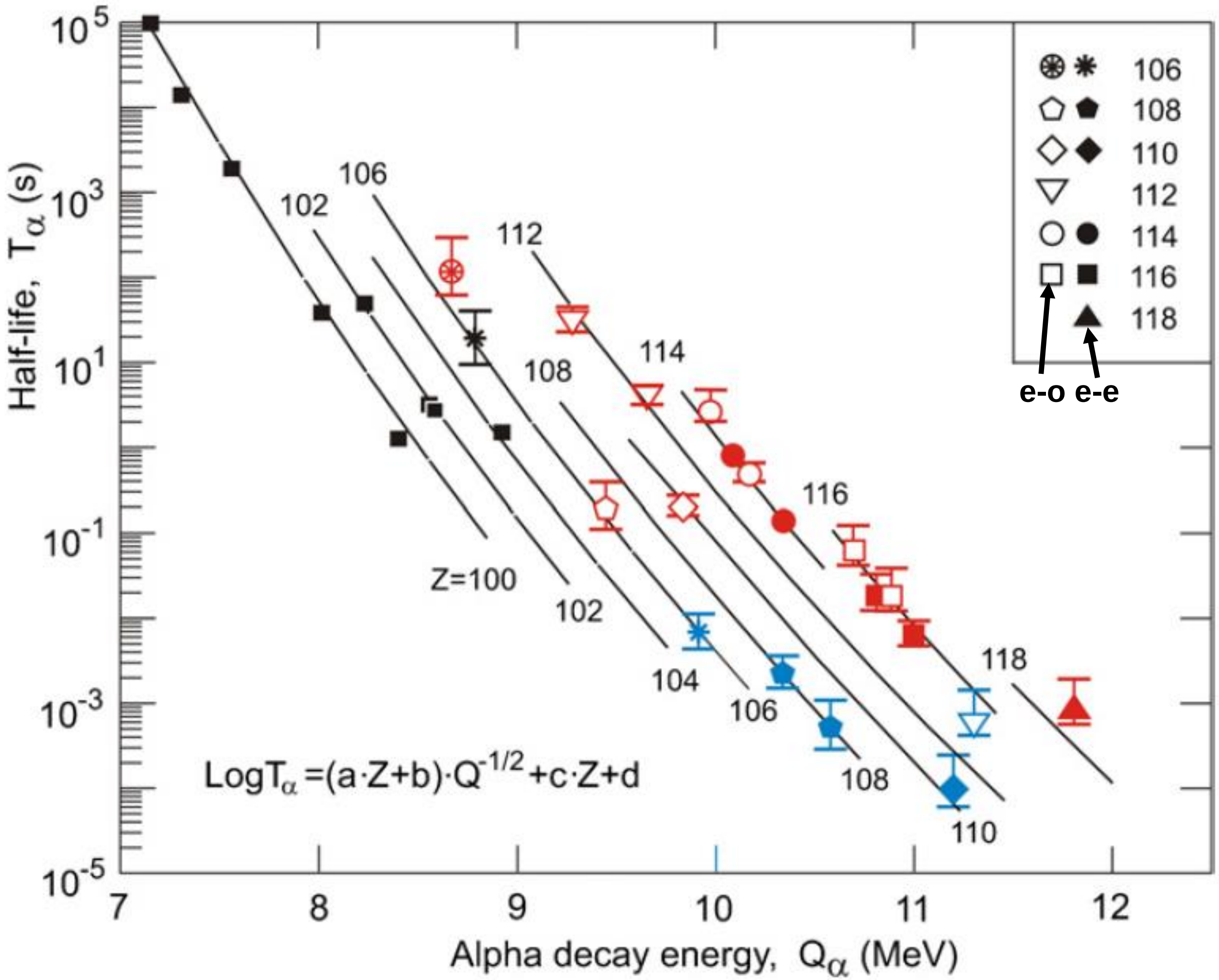


Note production of $^{294}118$ from ^{249}Cf in-growth in target!

At the time of production, the target was 28% ^{249}Cf

Excitation functions for these reactions have been measured

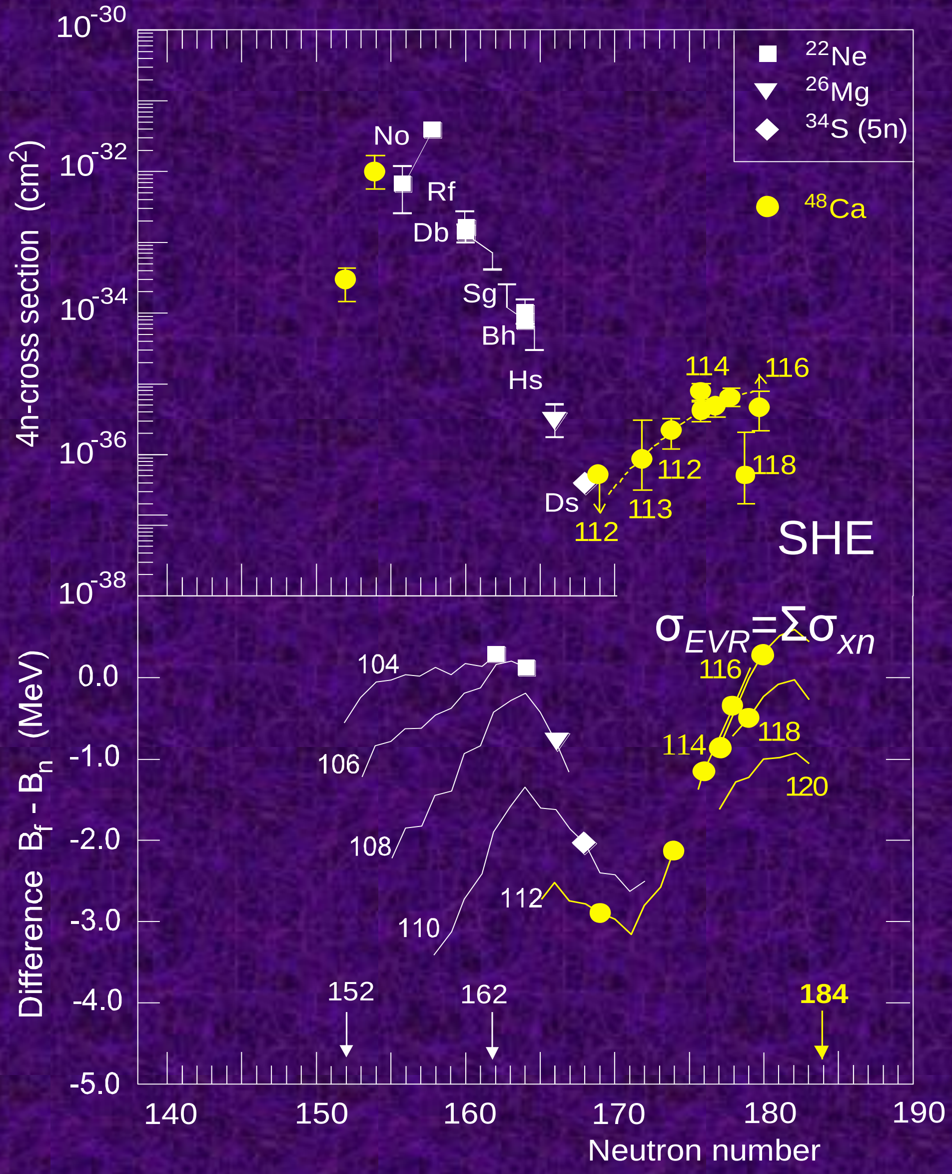
The average decay properties of the even-mass decay chains match the Geiger-Nuttall relationship



Comparison of 4n-evaporation cross-section with fission barrier

E_x=35-40 MeV

hot fusion



Systematics indicate clearly we are approaching the "Island of Stability"

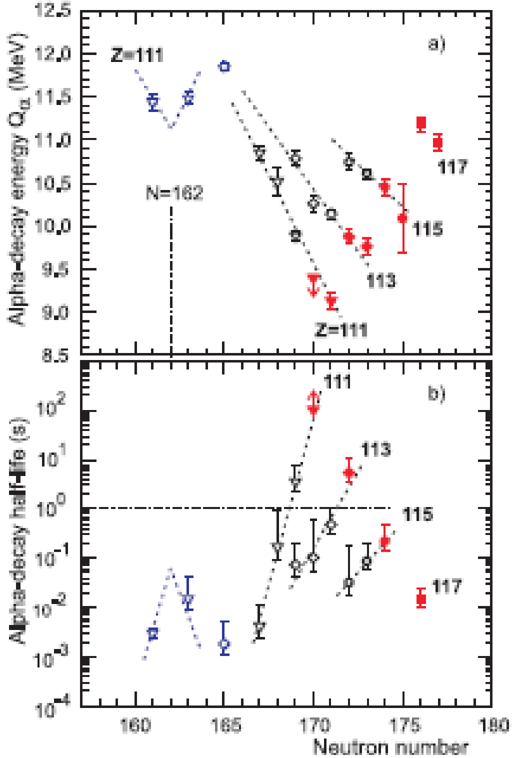
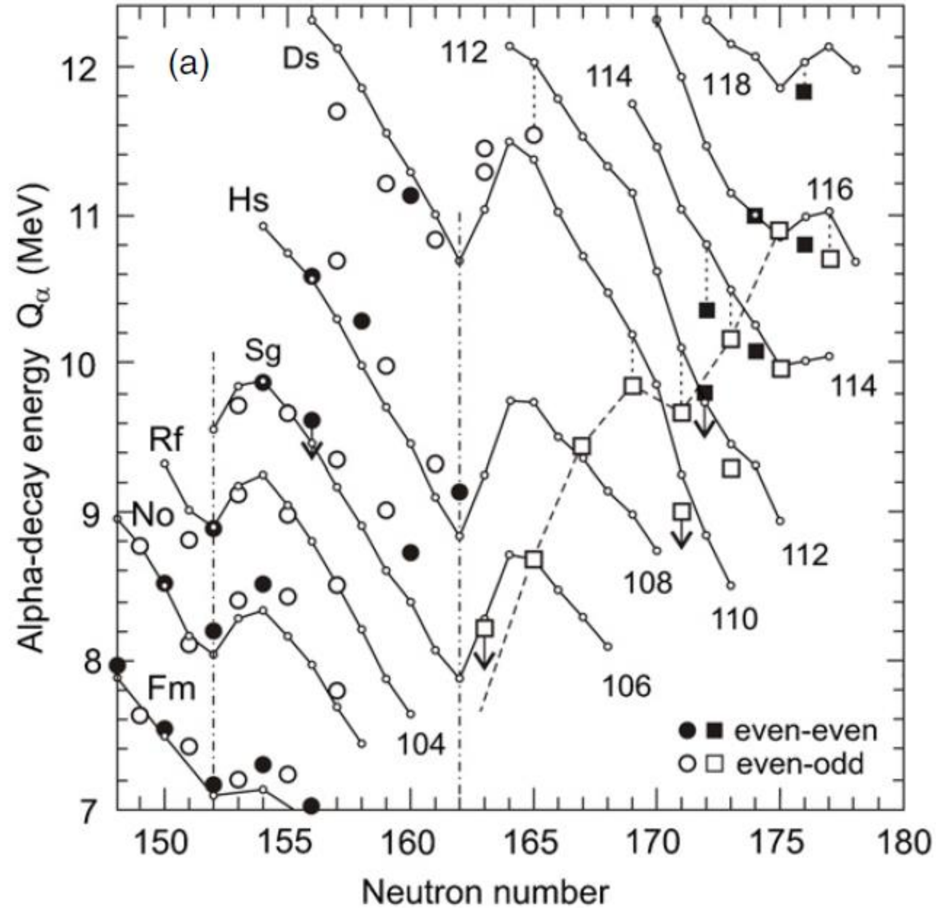
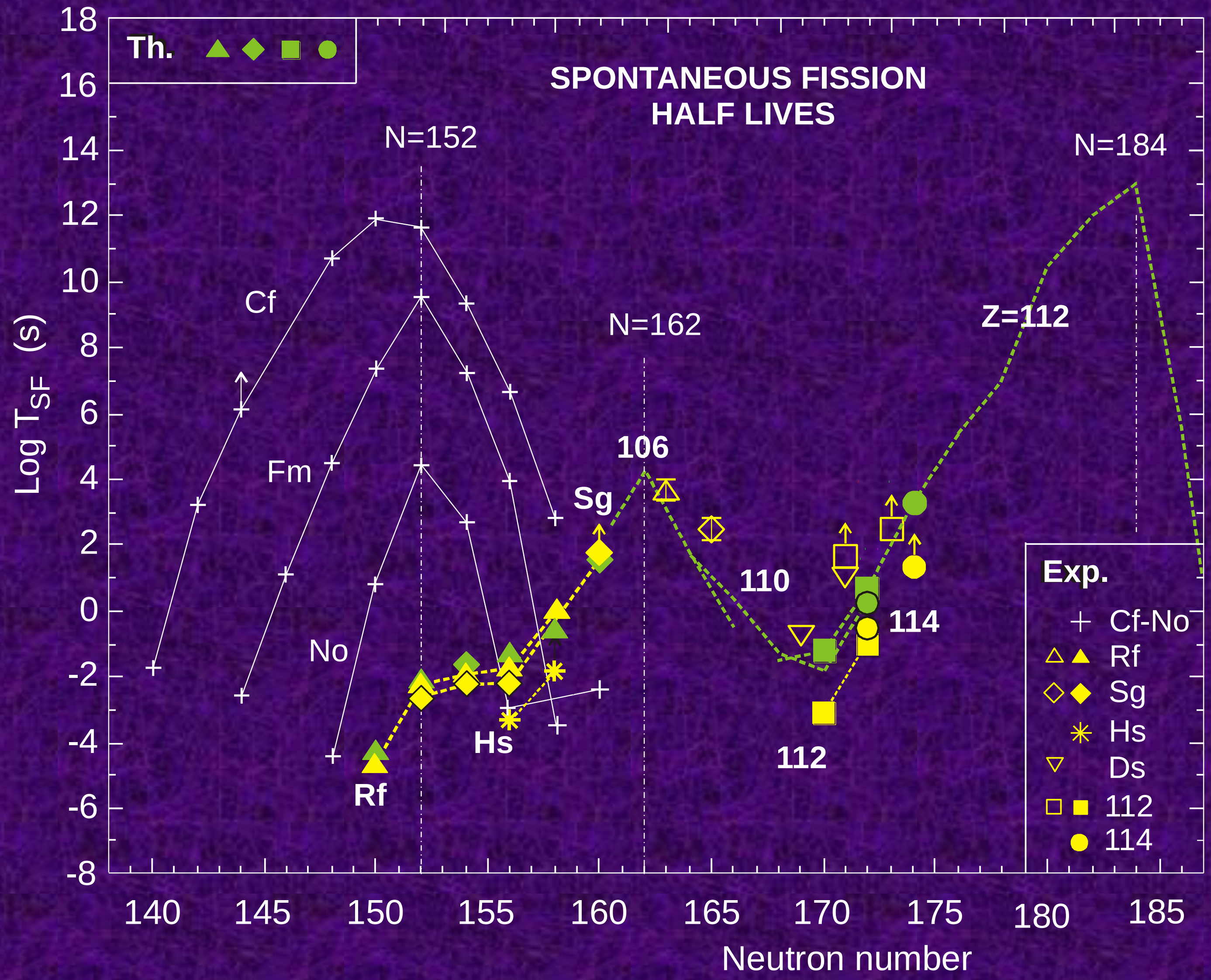


FIG. 3: a) Alpha-decay energy and b) half lives vs. neutron number for the isotopes of elements with Z =111-117 (new results in red). All the nuclides with N>165 have been produced in ^{48}Ca induced reactions. Our T_α(exp) values are given for the nuclei belonging to the ^{293}117 decay chain (5 events). The limit for $T_\alpha(^{281}Rg)$ was estimated from the measured half-life and number of observed nuclei.



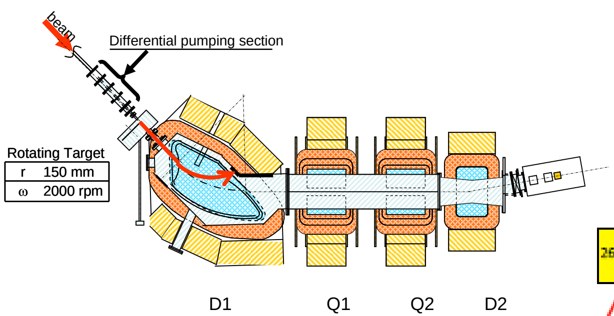
Spontaneous fission half-lives also indicate shell closure

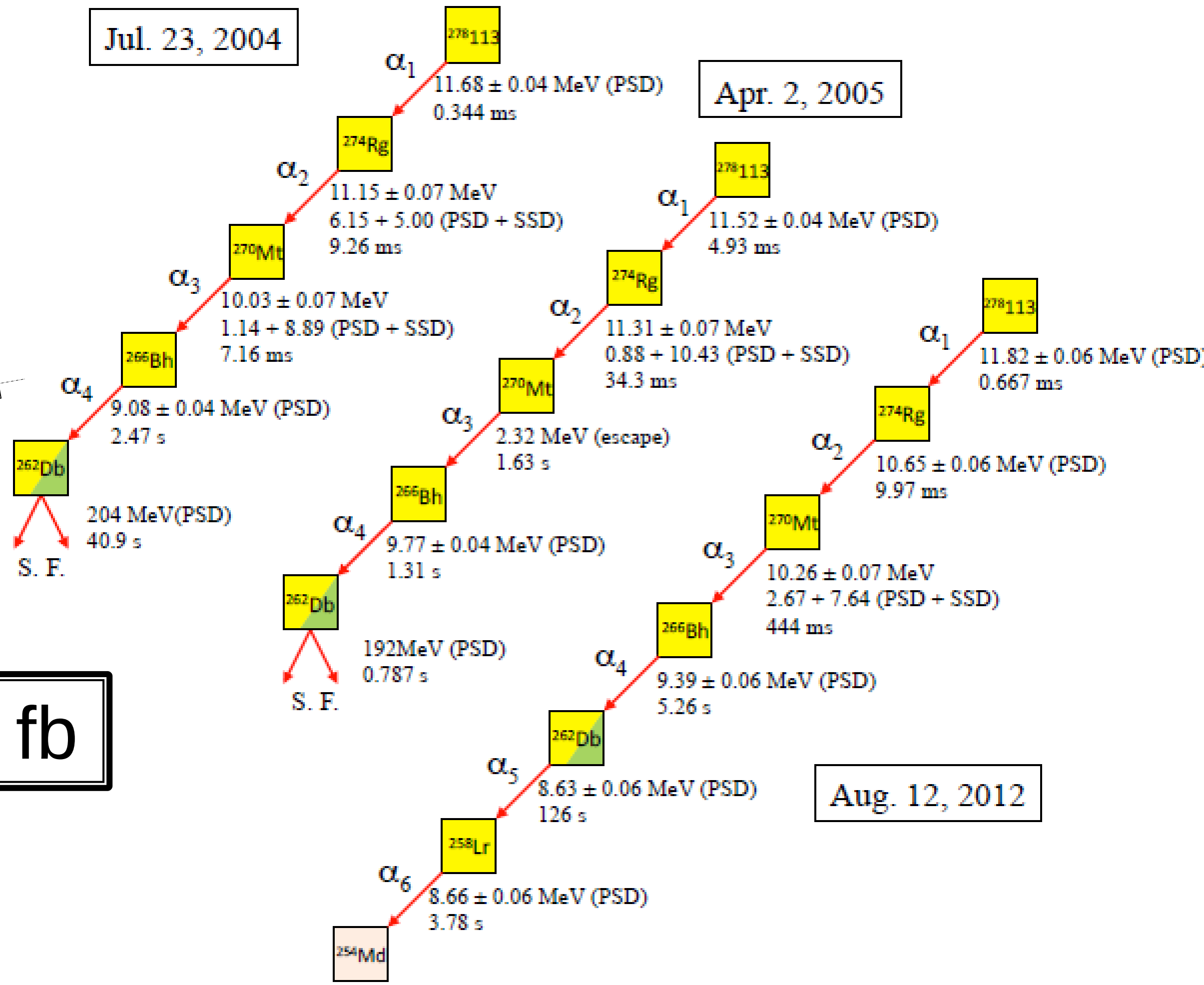


Cold fusion reactions produced some isotopes of element 113 at RIKEN

$$^{209}\mathrm{Bi} + {}^{70}\mathrm{Zn} \rightarrow {}^{278}113 + n$$

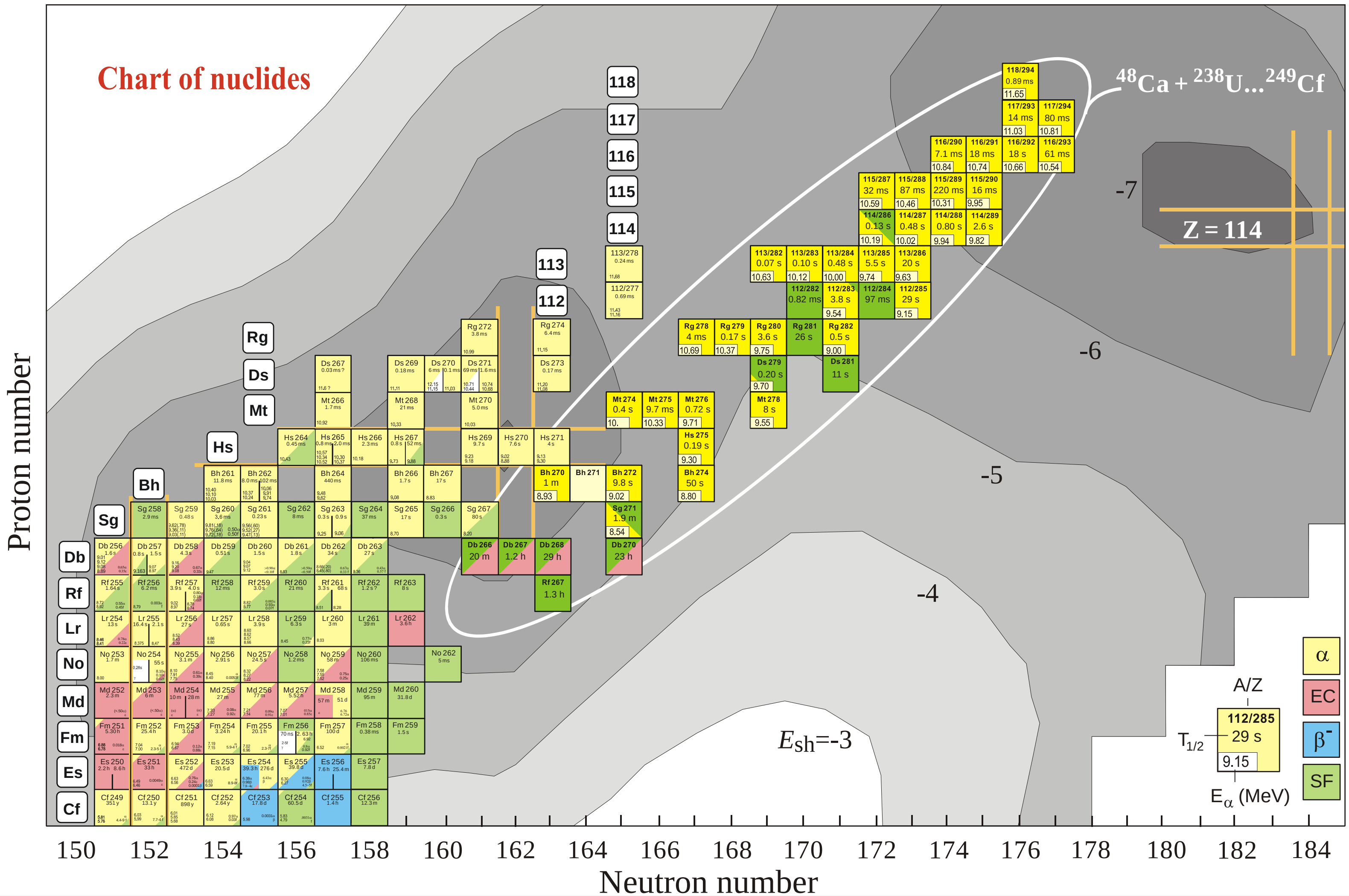
GARIS





$$\sigma_{1n} = 22^{+20}_{-13}\ \mathrm{fb}$$

The chart of nuclides in 2010



The Super Heavy Element Factory in Dubna is under construction and will be operational in 2015

The SHEF will include a new cyclotron

ACCELERATORS

Beam parameters	HI-Physics U-400R	SHE-Factory DC-280
Projectiles	Stable and RIB ($T_{1/2}$ > 0.1s)	Stable only
Projectile masses	4He – 238U	40Ar – 86Kr
Energy range	0.5 – 27.0 MeV/n	5 – 8 MeV/n
Energy resolution	0.5%	1.5%
Beam intensity (for 48Ca)	2.5 pμA	10-20 pμA
SHE-research program	≤30%	~100%
Registered decay chains of SHN (per year)	120 (now 30)	~5000
State of readiness	75%	In course of design

150 times more SHE!

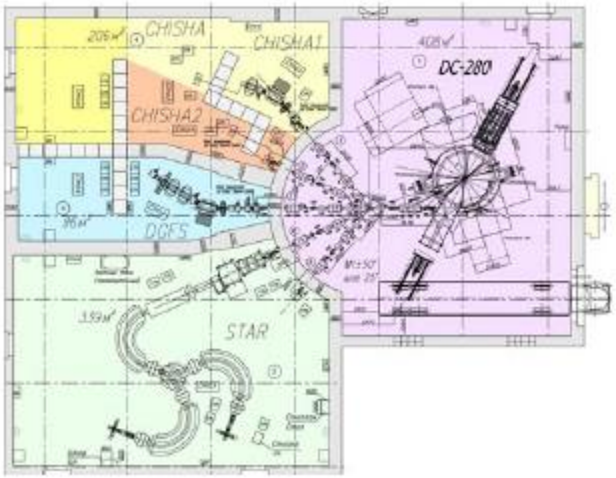


Figure 5: The layout of the DC-280 cyclotron complex.

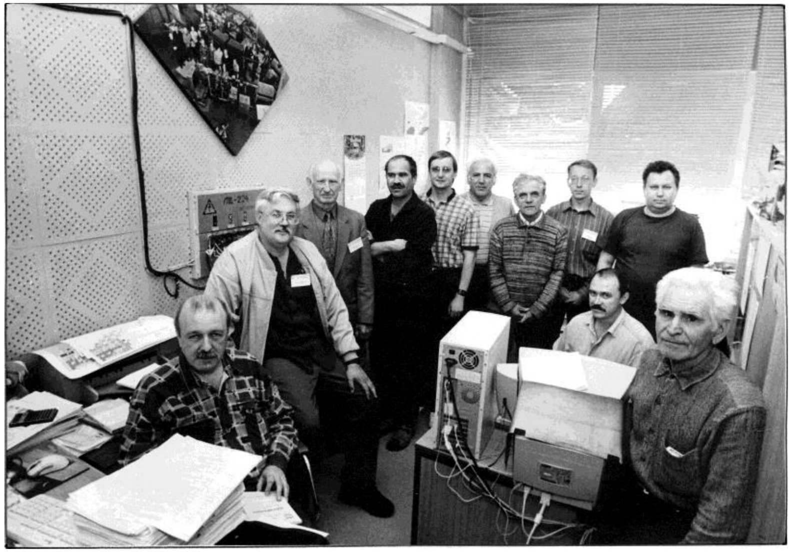
Table 3: Main Parameters of The DC-280

Injecting beam potential	Up to 100 kV
Pole diameter	4000 mm
A/Z range of accelerated ions	4÷7
Magnetic field	0.65÷1.27 T
K factor	220
Gap between plugs	320 mm
Valley/hill gap	400/300 mm/mm
Magnet weight	915 t
Magnet power	270 kW
Dee voltage	2x130 kV
RF power consumption	2x30 kW
Flat-top dee voltage	2x14 kV
Beam orbit separation	10 mm
Radial beam bunch size	3 mm
Efficiency of beam transfer	60%
Total accelerating potential	up to ~ 40 MV

Significant new opportunities for study of the heaviest elements will exist

We have been collaborating with Dubna on SHE research since 1989



The chemistry of an element, and its adherence or lack thereof to periodicity, is a fundamental scientific question

Periodic Table 1-172

Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Orbitals
1	1 H																	2 He	1s
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne	2s2p
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar	3s3p
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr	4s3d4p
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe	5s4d5p
6	55 Cs	56 Ba	57-71	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn	6s5d6p
7	87 Fr	88 Ra	89-103	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113	114	115	116	117	118	7s6d7p
8	119	120	121-	156	157	158	159	160	161	162	163	164	139	140	169	170	171	172	8s7d8p
9	165	166											167	168					9s9p

Period																Orbitals
6	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu	4f
7	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr	5f
8	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	6f

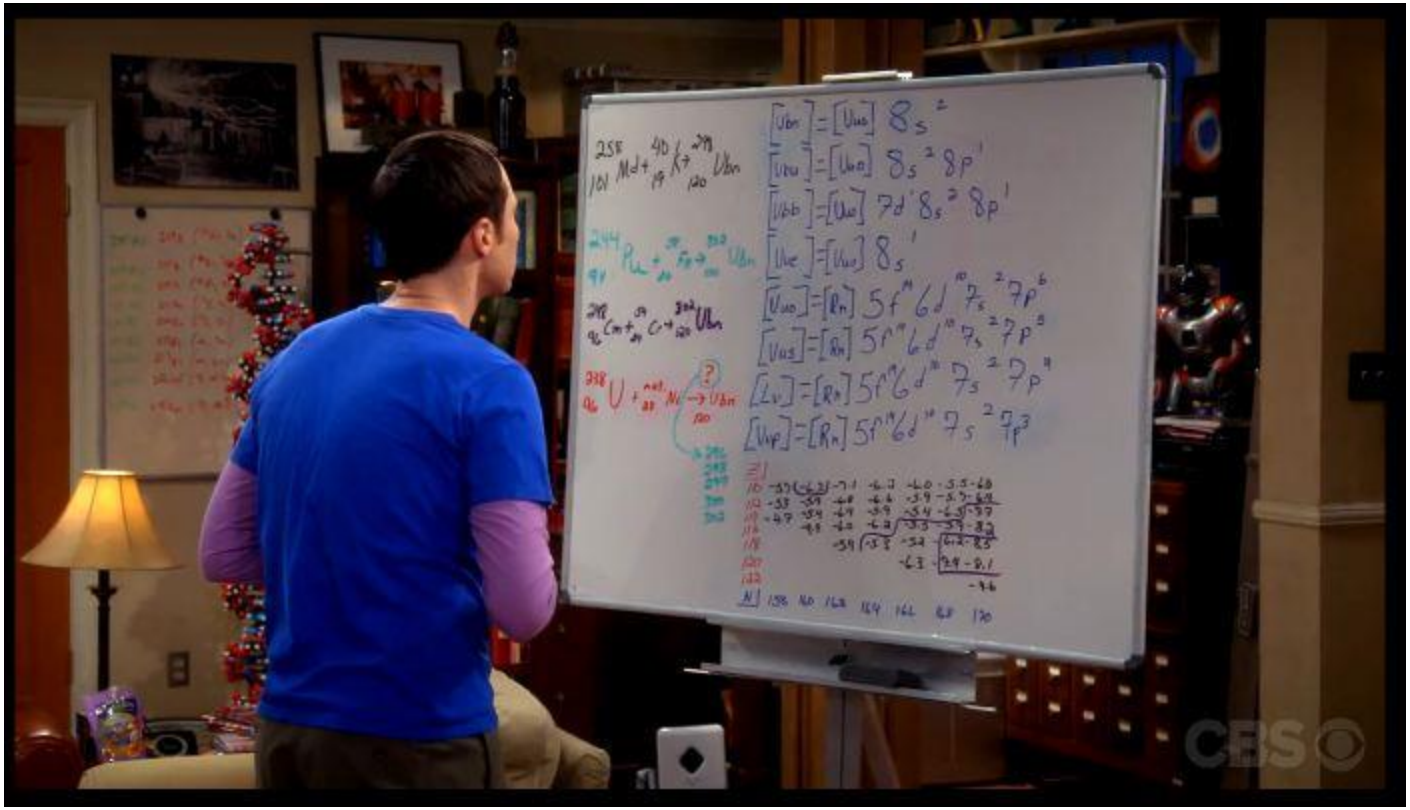
Period																			Orbitals
8	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	5g

Elements for which no chemical info known

Elements don't have to fit into the periodic table in this way!

P. Pyykkö, Phys. Chem. Chem. Phys. **13**, 161 (2011)

Recent episode of The Big Bang Theory had Sheldon theoretically discovering a stable SHE



Season 7 (2013) – “The Romance Resonance”

Which of Sheldon's four reactions would you use to make element 120?

A) $^{258}Md + ^{40}K \rightarrow ^{298}120^*$

B) $^{244}Pu + ^{58}Fe \rightarrow ^{302}120^*$

C) $^{248}Cm + ^{54}Cr \rightarrow ^{302}120^*$

D) $^{238}U + ^{64}Ni \rightarrow ^{302}120^*$

Answer: All but A have been tried, Md target not possible – $t_{1/2} = 51d$

Conclusions

- For even-Z nuclei with Z>113, there are 4 isotopes each of Fl and Lv, and one isotope of element 118 known
- Tantalizing hint of a fifth isotope of Fl, but evidence is weak (only one SF event)
- Exploration of the limits of nuclear and chemical stability continue – planned experiment with ^{240}Pu and ^{251}Cf targets
- Jackie Gates will talk about experiments to explore the nuclear structure of the heaviest elements and try to identify elements by detecting x-rays

Acknowledgements

- Russian Foundation for Basic Research under grant No. 96-02-17377
- INTAS under grant No. 96-662
- U.S. DOE under contract No. DE-AC52-07NA27344
- Some actinides provided by the U.S. DOE through ORNL
- Performed in the framework of Russian Federation/U.S. Joint Coordinating Committee for Research on Fundamental Properties of Matter

I am of course discussing the work of many

- LLNL (Heavy Elements Group) – Ken Moody, John Wild, Ron Lougheed, Mark Stoyer, Nancy Stoyer, Carola Laue, Dawn Shaughnessy, Jerry Landrum, Joshua Patin, Philip Wilk, Roger Henderson, Sarah Nelson
- JINR, Dubna, Russia – Yu. Ts. Oganessian, V.K. Utyonkov, Yu. V. Lobanov, F.Sh. Abdullin, A.N. Polykov, I.V. Shirokovsky, Yu.S. Tsyganov, G.G. Gulbekian, S.L. Bogomolov, B.N. Gikal, A.N. Mezentsev, S. Iliev, V.G. Subbotin, A.M. Sukhov, G.V. Buklanov, K. Subotic, M.G. Itkis, R.N. Sagaidak, S. Shishkin, A.A. Voinov, V.I. Zagrebaev, and S.N. Dmitriev
- ORNL – C. Alexander, J. Binder, R. A. Boll, J. Ezold, K. Felker, R. K. Grzywacz, K. Miernik, J. B. Roberto, K. P. Rykaczewski
- Vanderbilt University – J.H. Hamilton, A.V. Ramayya
- RIAR, Dimitrovgrad, Russia – M. A. Ryabinin
- UNLV, ANL, TAMU more recent additions to the collaboration