JINR
114 Flerovium
FLNR
Dubna

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RESEARCH

NEUTRON EMISSION FROM SPONTANEOUS FISSION OF HEAVY ELEMENTS

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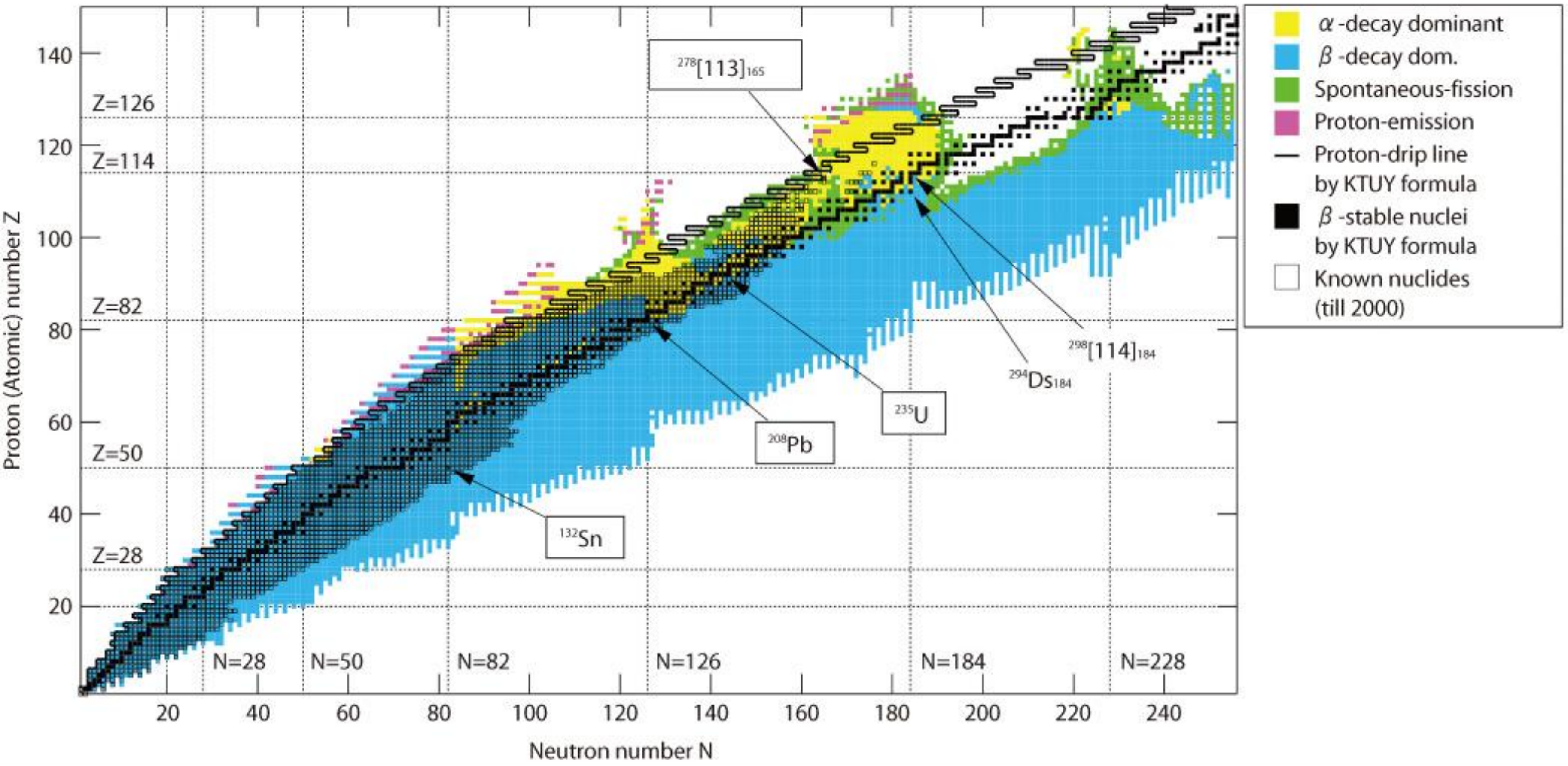
Super Heavy Elements

Super-heavy elements, (**SHE**) usually refer to the transuranium elements with atomic number higher than 92. All of these elements are unstable and decay radioactively into other elements.

The important decay mode for SHE is „Spontaneous Fission” [marked green in diagram].



Super Heavy Elements

- SHE have only been made artificially, and their short half-lives cause them to decay after a very short time, ranging from a few minutes to just a few milliseconds (except for dubnium, which has a half life of over a day.
- Super-heavy atoms are created through the bombardment of elements in a particle accelerator.

Some of the SHE elements were discovered in FLNR

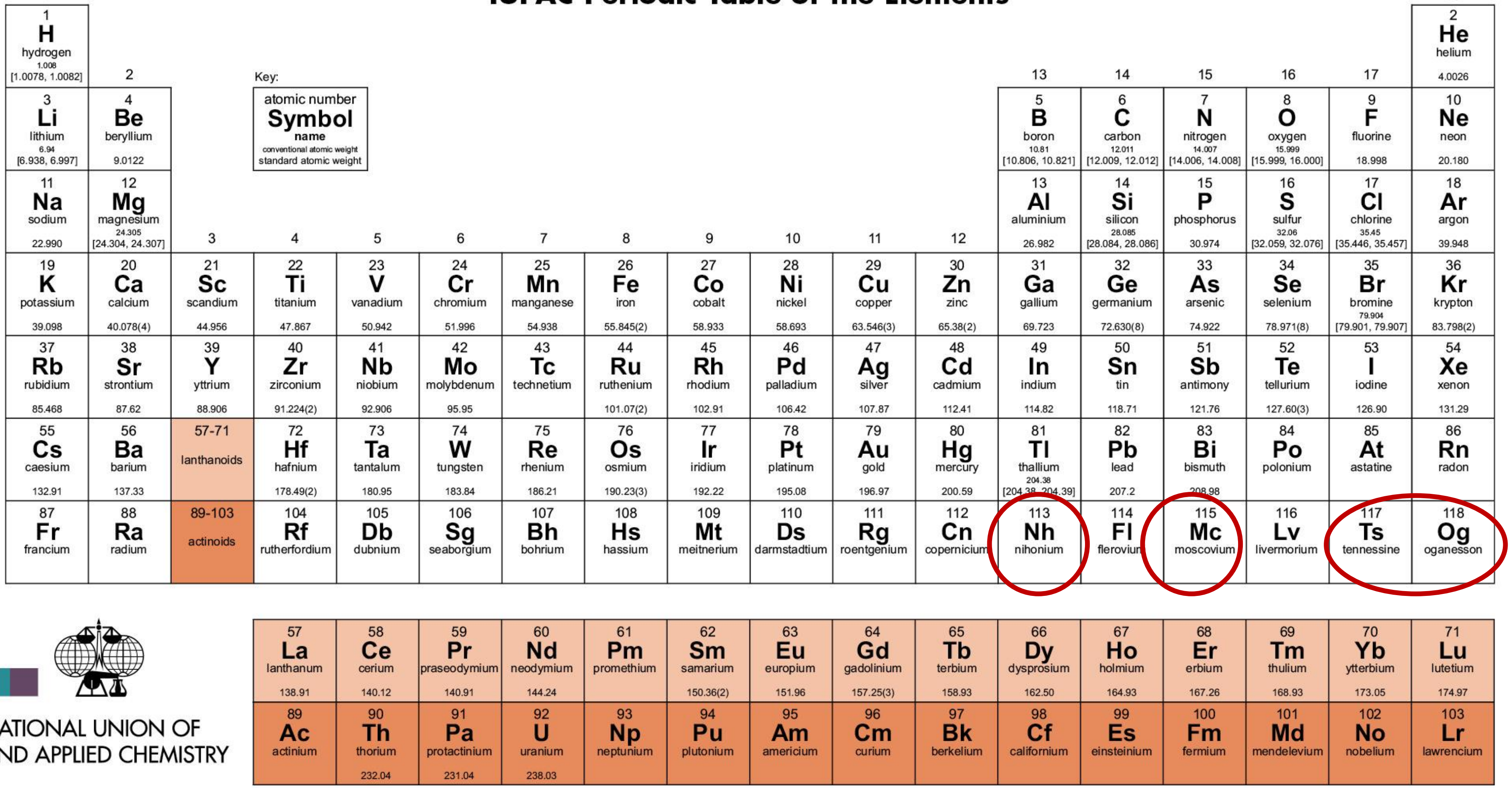
New super heavy elements discovered

The latest release of the Periodic Table (dated 28 November 2016) includes the recently added elements 113, 115, 117, and 118 with their names and symbols.

The International Union of Pure and Applied Chemistry has announced these proposed names:

- Nihonium and symbol Nh, for the element 113
- Moscovium and symbol Mc, for the element 115
- Tennessine and symbol Ts, for the element 117
- Oganesson and symbol Og, for the element 118

IUPAC Periodic Table of the Elements



Key:
atomic number
Symbol
name
conventional atomic weight
standard atomic weight

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 **H** hydrogen 1.008 [1.0078, 1.0082]																	2 **He** helium 4.0026
3 **Li** lithium 6.94 [6.938, 6.997]	4 **Be** beryllium 9.0122											5 **B** boron 10.81 [10.806, 10.821]	6 **C** carbon 12.011 [12.009, 12.012]	7 **N** nitrogen 14.007 [14.006, 14.008]	8 **O** oxygen 15.999 [15.999, 16.000]	9 **F** fluorine 18.998	10 **Ne** neon 20.180
11 **Na** sodium 22.990	12 **Mg** magnesium 24.305 [24.304, 24.307]											13 **Al** aluminium 26.982	14 **Si** silicon 28.085 [28.084, 28.086]	15 **P** phosphorus 30.974	16 **S** sulfur 32.06 [32.059, 32.076]	17 **Cl** chlorine 35.45 [35.446, 35.457]	18 **Ar** argon 39.948
19 **K** potassium 39.098	20 **Ca** calcium 40.078(4)	21 **Sc** scandium 44.956	22 **Ti** titanium 47.867	23 **V** vanadium 50.942	24 **Cr** chromium 51.996	25 **Mn** manganese 54.938	26 **Fe** iron 55.845(2)	27 **Co** cobalt 58.933	28 **Ni** nickel 58.693	29 **Cu** copper 63.546(3)	30 **Zn** zinc 65.38(2)	31 **Ga** gallium 69.723	32 **Ge** germanium 72.630(8)	33 **As** arsenic 74.922	34 **Se** selenium 78.971(8)	35 **Br** bromine 79.904 [79.901, 79.907]	36 **Kr** krypton 83.798(2)
37 **Rb** rubidium 85.468	38 **Sr** strontium 87.62	39 **Y** yttrium 88.906	40 **Zr** zirconium 91.224(2)	41 **Nb** niobium 92.906	42 **Mo** molybdenum 95.95	43 **Tc** technetium	44 **Ru** ruthenium 101.07(2)	45 **Rh** rhodium 102.91	46 **Pd** palladium 106.42	47 **Ag** silver 107.87	48 **Cd** cadmium 112.41	49 **In** indium 114.82	50 **Sn** tin 118.71	51 **Sb** antimony 121.76	52 **Te** tellurium 127.60(3)	53 **I** iodine 126.90	54 **Xe** xenon 131.29
55 **Cs** caesium 132.91	56 **Ba** barium 137.33	57-71 lanthanoids	72 **Hf** hafnium 178.49(2)	73 **Ta** tantalum 180.95	74 **W** tungsten 183.84	75 **Re** rhenium 186.21	76 **Os** osmium 190.23(3)	77 **Ir** iridium 192.22	78 **Pt** platinum 195.08	79 **Au** gold 196.97	80 **Hg** mercury 200.59	81 **Tl** thallium 204.38 [204.38, 204.39]	82 **Pb** lead 207.2	83 **Bi** bismuth 208.98	84 **Po** polonium	85 **At** astatine	86 **Rn** radon
87 **Fr** francium	88 **Ra** radium	89-103 actinoids	104 **Rf** rutherfordium	105 **Db** dubnium	106 **Sg** seaborgium	107 **Bh** bohrium	108 **Hs** hassium	109 **Mt** meitnerium	110 **Ds** darmstadtium	111 **Rg** roentgenium	112 **Cn** copernicium	113 **Nh** nihonium	114 **Fl** flerovium	115 **Mc** moscovium	116 **Lv** livermorium	117 **Ts** tennessine	118 **Og** oganesson

57 **La** lanthanum 138.91	58 **Ce** cerium 140.12	59 **Pr** praseodymium 140.91	60 **Nd** neodymium 144.24	61 **Pm** promethium	62 **Sm** samarium 150.36(2)	63 **Eu** europium 151.96	64 **Gd** gadolinium 157.25(3)	65 **Tb** terbium 158.93	66 **Dy** dysprosium 162.50	67 **Ho** holmium 164.93	68 **Er** erbium 167.26	69 **Tm** thulium 168.93	70 **Yb** ytterbium 173.05	71 **Lu** lutetium 174.97
89 **Ac** actinium	90 **Th** thorium 232.04	91 **Pa** protactinium 231.04	92 **U** uranium 238.03	93 **Np** neptunium	94 **Pu** plutonium	95 **Am** americium	96 **Cm** curium	97 **Bk** berkelium	98 **Cf** californium	99 **Es** einsteinium	100 **Fm** fermium	101 **Md** mendelevium	102 **No** nobelium	103 **Lr** lawrencium

INTERNATIONAL UNION OF
PURE AND APPLIED CHEMISTRY

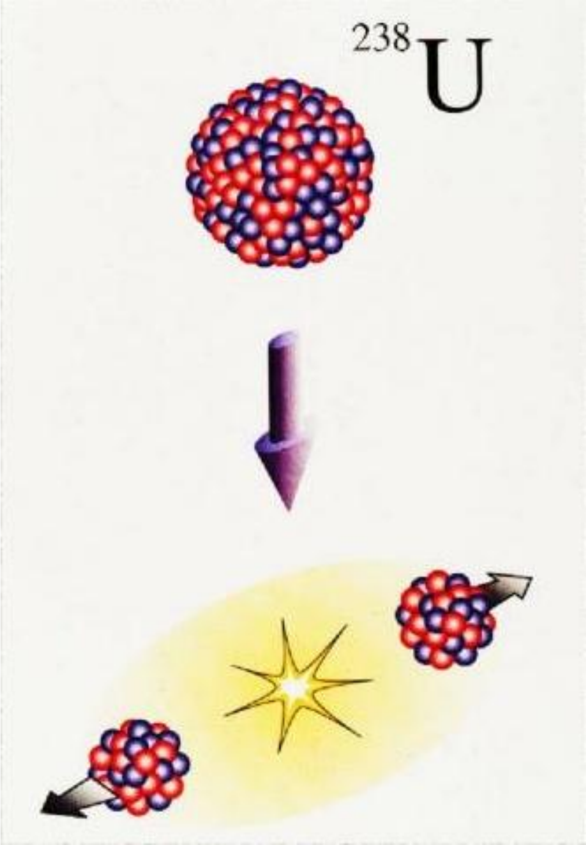
For notes and updates to this table, see www.iupac.org. This version is dated 28 November 2016.

Creation of superheavy elements

- For production of superheavy elements you need:
  - ion source
  - accelerator
  - target
- Separation and detection of the reaction products:
  - separation filter
  - detector system for α decay

Spontaneus fission

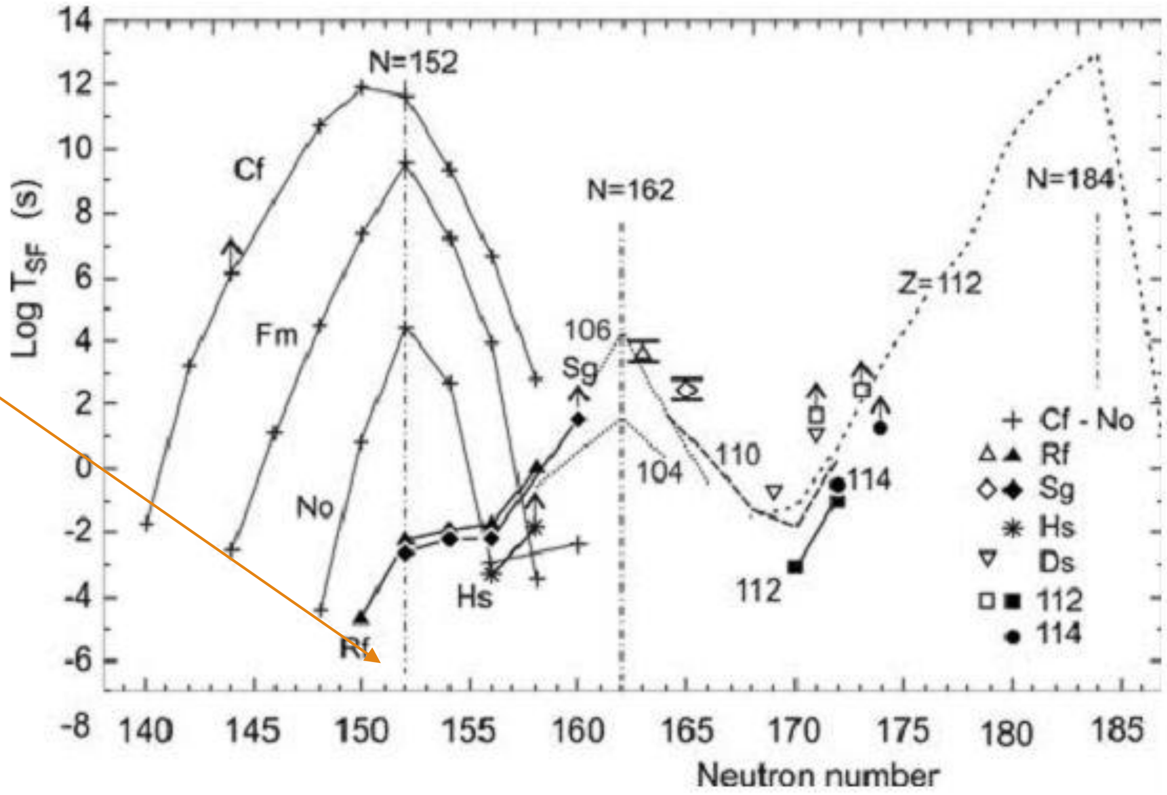
- Spontaneous fission is a form of radioactive decay where an atom's nucleus splits into two smaller nuclei and generally one or more neutrons.
- The reason fission occurs is that energy upsets the balance between the electrostatic repulsion between positively-charge protons and the strong nuclear force that holds protons and neutrons together. The nucleus oscillates, so the repulsion may overcome the short-range attraction, causing the atom to split.
- Spontaneous fission generally occurs in atoms with atomic numbers above 90.
- For example, uranium-238 decays by alpha decay with a half-life on the order of 10^9 years, but also decays by spontaneous fission on the order of 10^{16} years.



Spontaneous fission of heavy elements

SF Halflives for SHE show strong dependence on so called “magic numbers”.

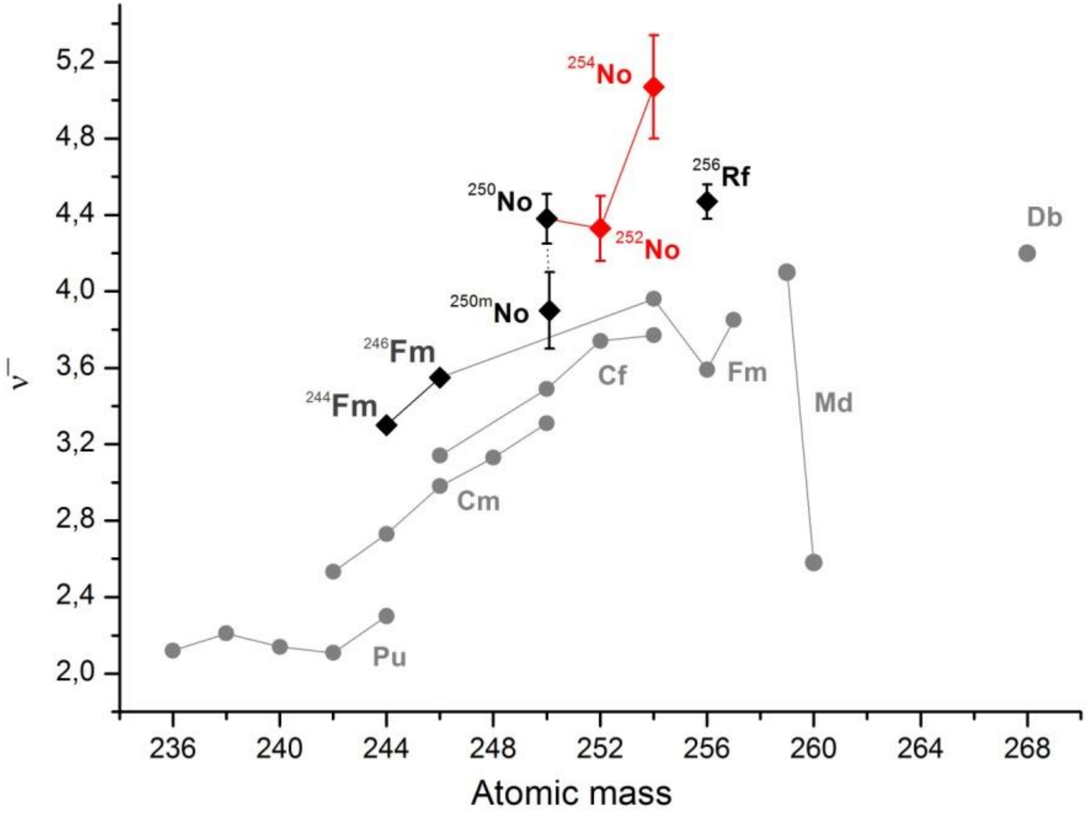
The numbers of nucleons needed to fill each successive shell are called the magic numbers: The traditional ones are 2, 8, 20, 28, 50, 82, and 126.



Multiplicity of prompt neutrons from SF

The multiplicity distribution of prompt neutrons is one of the important characteristics of spontaneous fission.

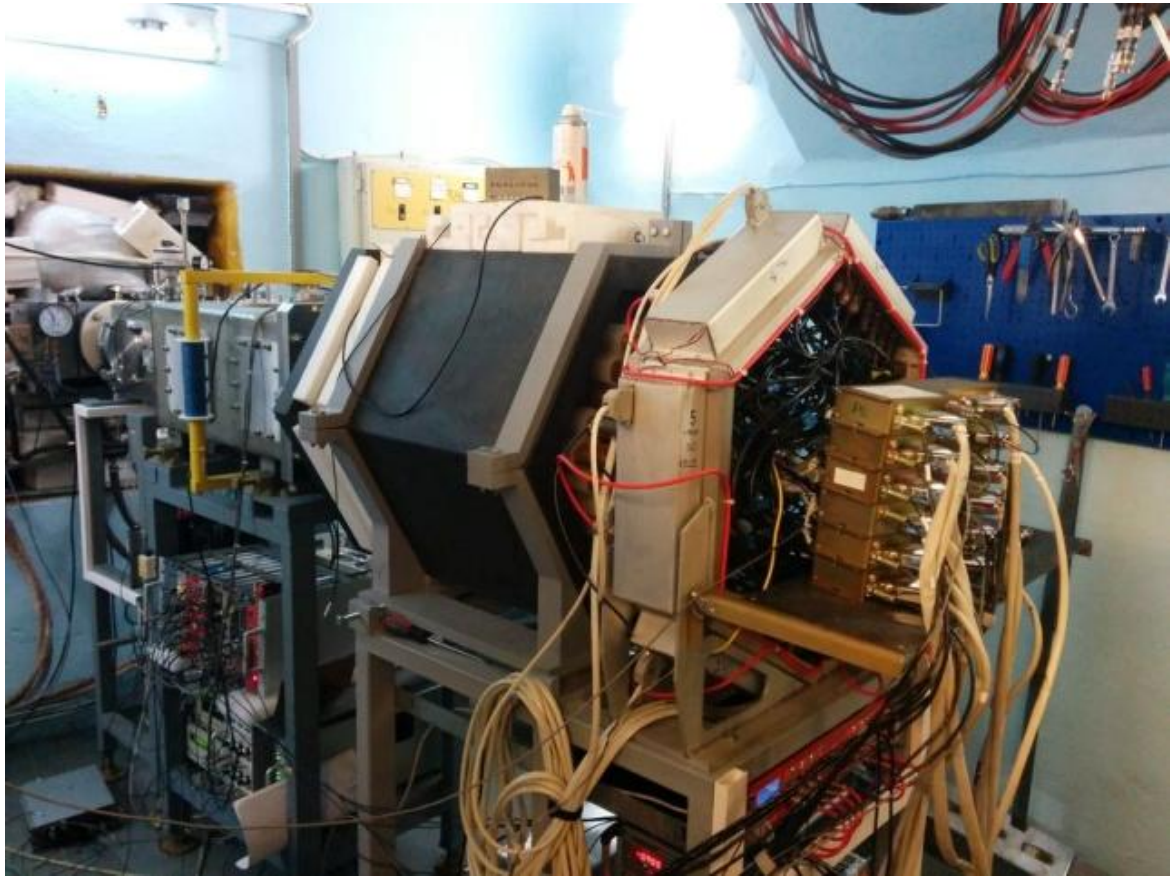
The number of neutrons emitted during fission directly depends on the degree of excitation of fission fragments and thus plays an important role in the restoration of the reaction energy balance and aids the exploration of the nuclear properties.

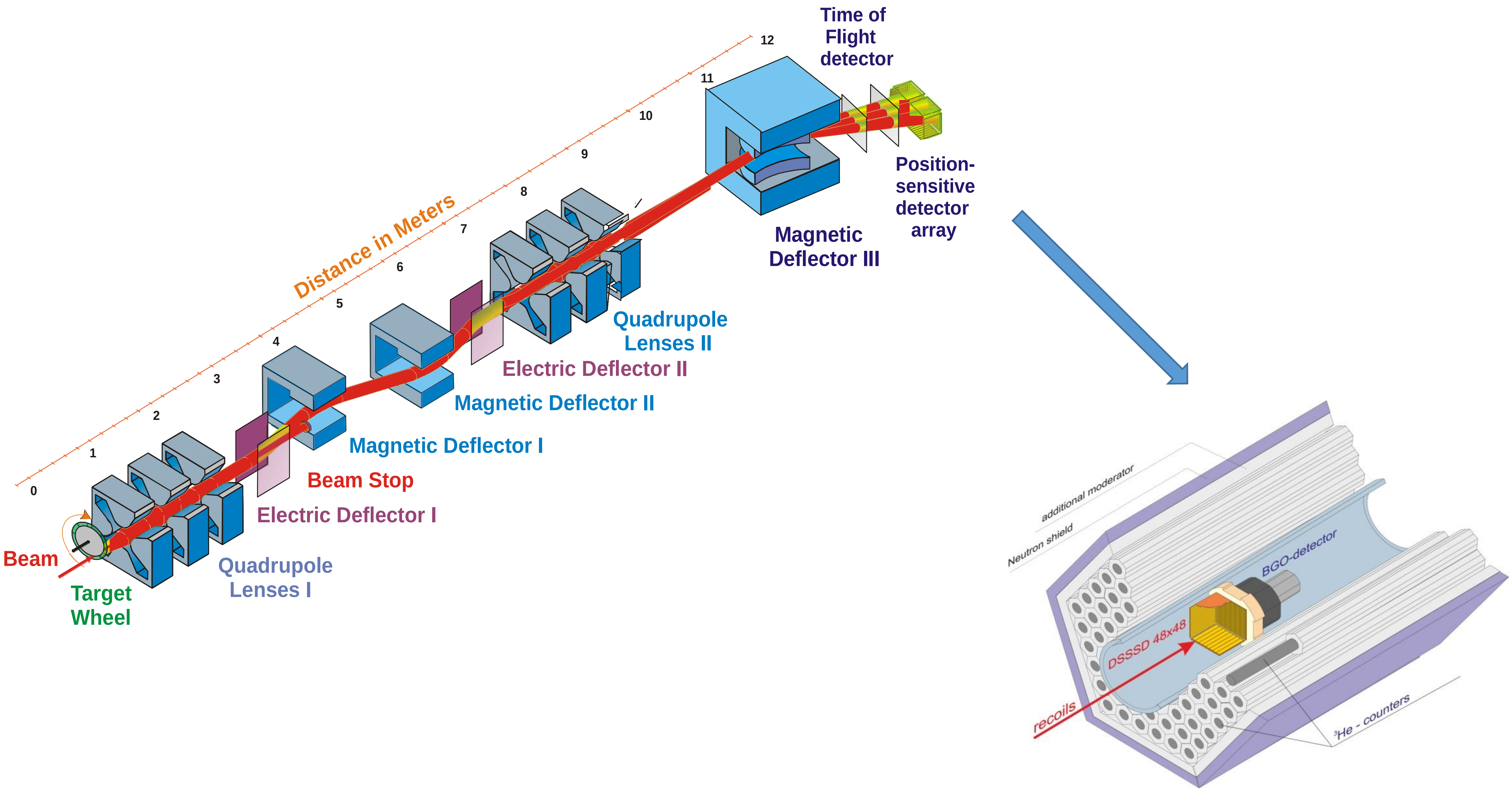


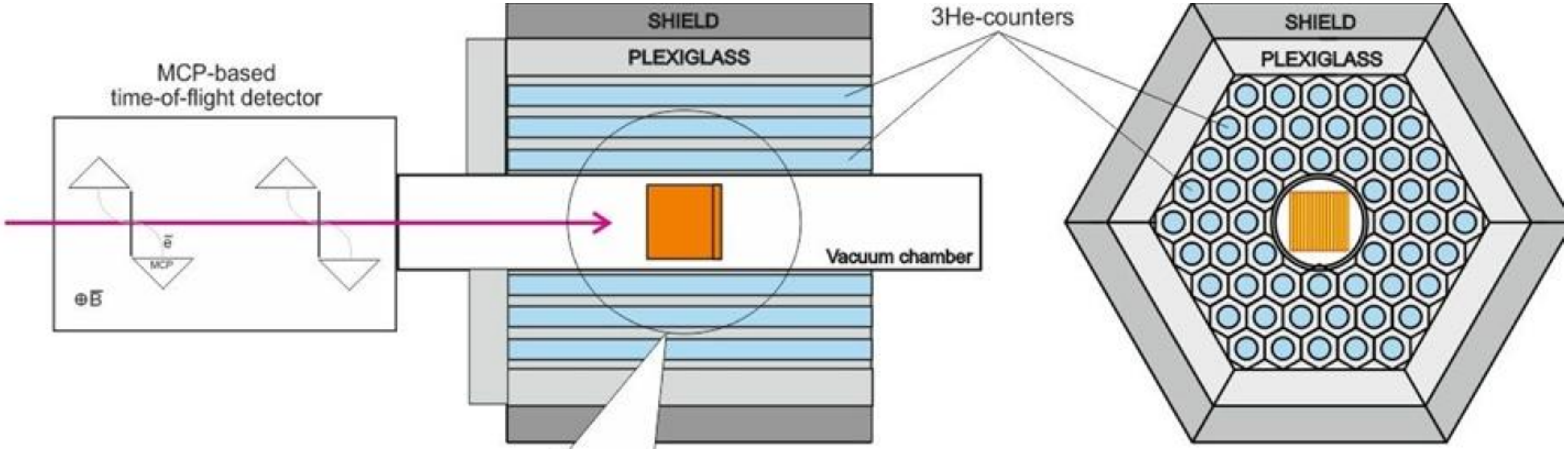
The average number of neutrons per fission as a function of the atomic mass.

Experimental setup

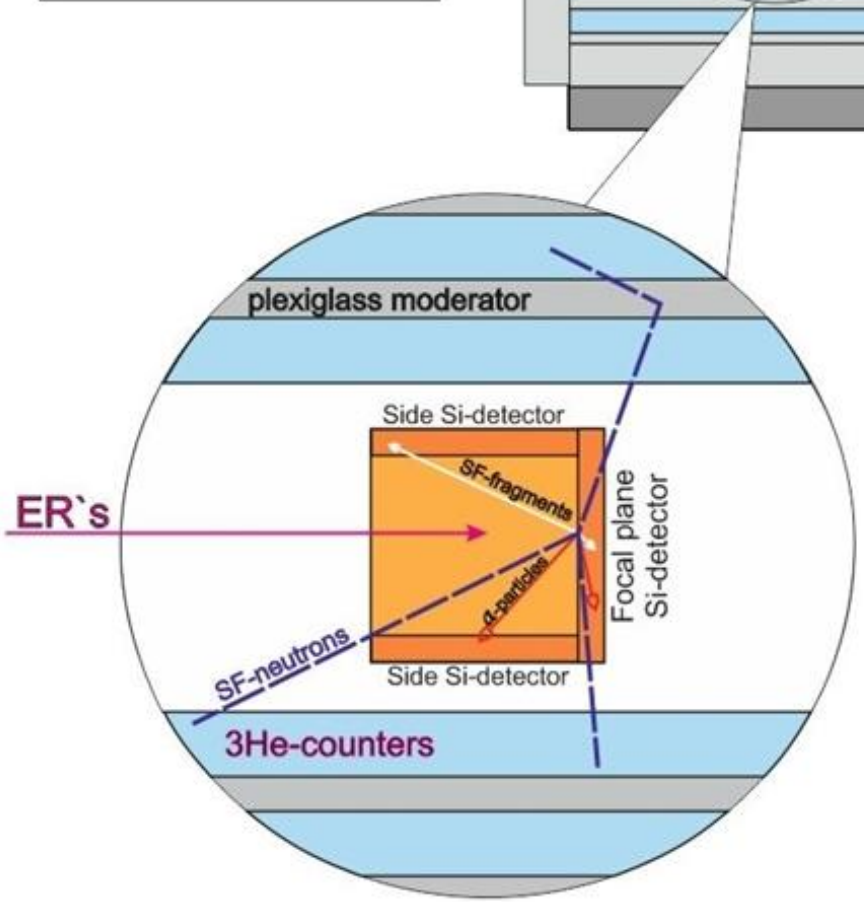
The detector system of the SHELS separator has been complemented with an array of 54 ^{3}He neutron counters to study the multiplicity of prompt spontaneous-fission neutrons.




Distance in Meters
0
1
2
3
4
5
6
7
8
9
10
11
12
Time of Flight detector
Position-sensitive detector array
Magnetic Deflector III
Quadrupole Lenses II
Electric Deflector II
Magnetic Deflector II
Magnetic Deflector I
Beam Stop
Electric Deflector I
Beam
Target Wheel
Quadrupole Lenses I
additional moderator
Neutron shield
BGO-detector
DSSSD 48x48
recoils
³He - counters



The focal plane Si-detector placed inside the neutron detector

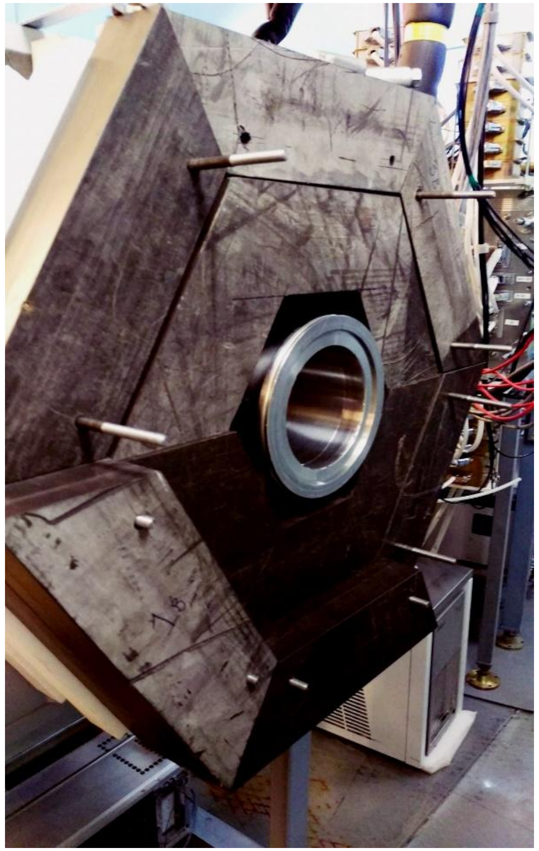


- ^{3}He-counters placed in moderator and surrounded by shield (polyethylene with boron)
  Dimensions of counters: D=30mm, L=500mm
  ^{3}He pressure – 8 At

  Efficiency for single neutrons: ***43.5 %***
  (^{248}Cm-source)

NEUTRON DETECTION

- Neutrons have mass but no electrical charge. Because of this they cannot directly produce ionization in a detector, and therefore cannot be directly detected.
- This means that neutron detectors must rely upon a conversion process where an incident neutron interacts with a nucleus to produce a secondary charged particle. These charged particles are then directly detected and from them the presence of neutrons is deduced.



He 3 counters

Prompt neutrons from SF have energies of 1 – 1,5 MeV – cross section 7 orders smaller

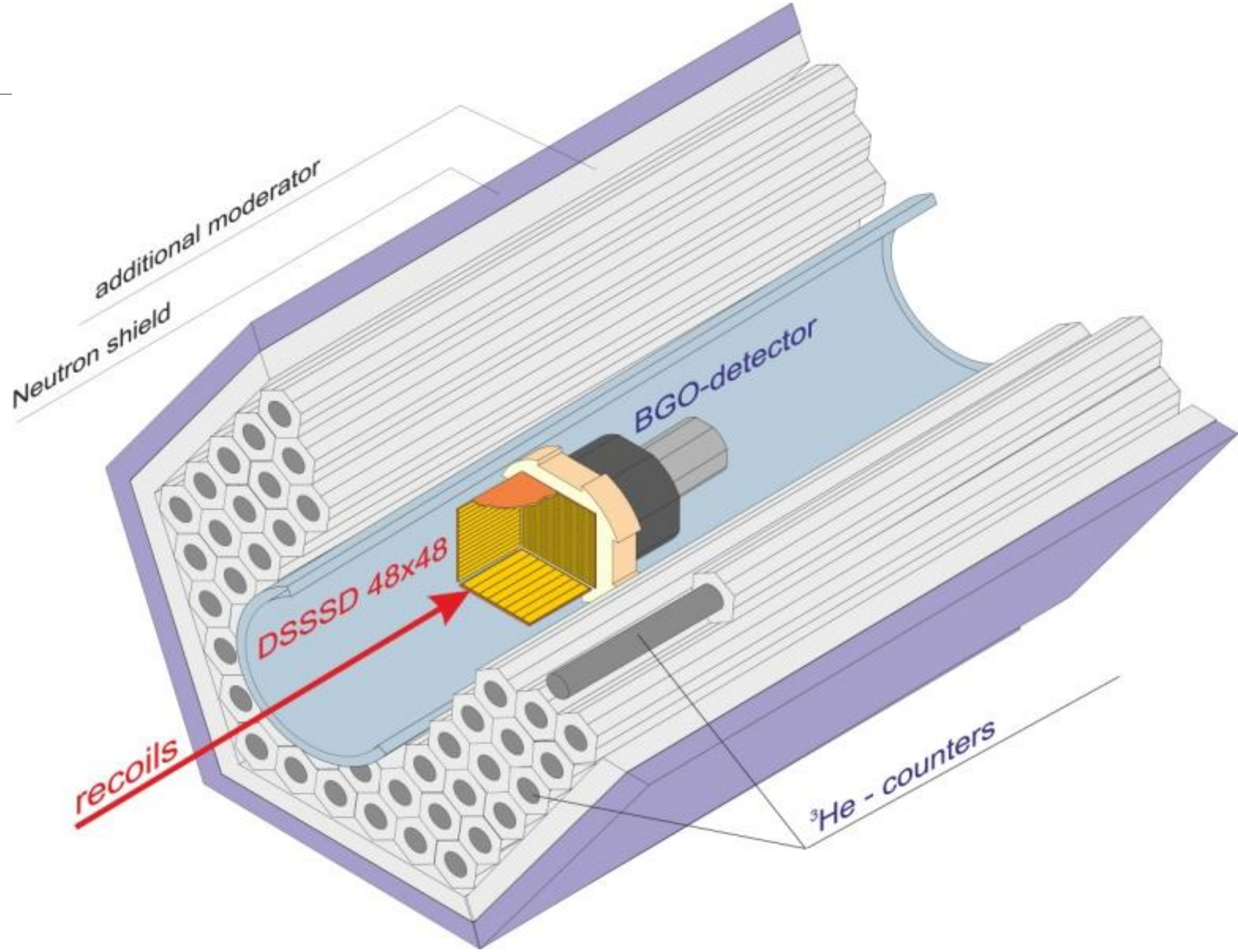
⟹ necessary to slow them down with polyethylene material

The most common reaction used for high efficiency thermal neutron detection today is:

n + 3He → p + 3H + 765 keV

where both the proton and the triton are detected by a gas filled proportional counter;

[cross section: 5400 barns – for thermal neutrons]



BGO detectors (Bismuth Germanate Scintillation)

- Bismuth Germanate (BGO) is a high Z, high density scintillation material with chemical composition Bi4Ge3O^{12}.
- Due to the high atomic number of bismuth (83) and its high density, BGO is a very efficient γ-ray absorber.

For our BGO detector:

Voltage	1000 V
Amplitude	2026
Coarse gain	20
Fine gain	5.8
Polarity	negative
Shaping time	0.5 µs

BGO detectors
(Bismuth Germanate Scintillation)

- The photopeak efficiency (also called the photofraction) – the ratio of the number of counts in the total absorption photopeak to the total number of counts as a function of the γ-ray energy for 38mm diameter, 38mm high (1.5" x 1.5") NaI(Tl) and BGO crystals.
- The decay time of BGO is about 300ns at room temperature, which is comparable to that of NaI(Tl).

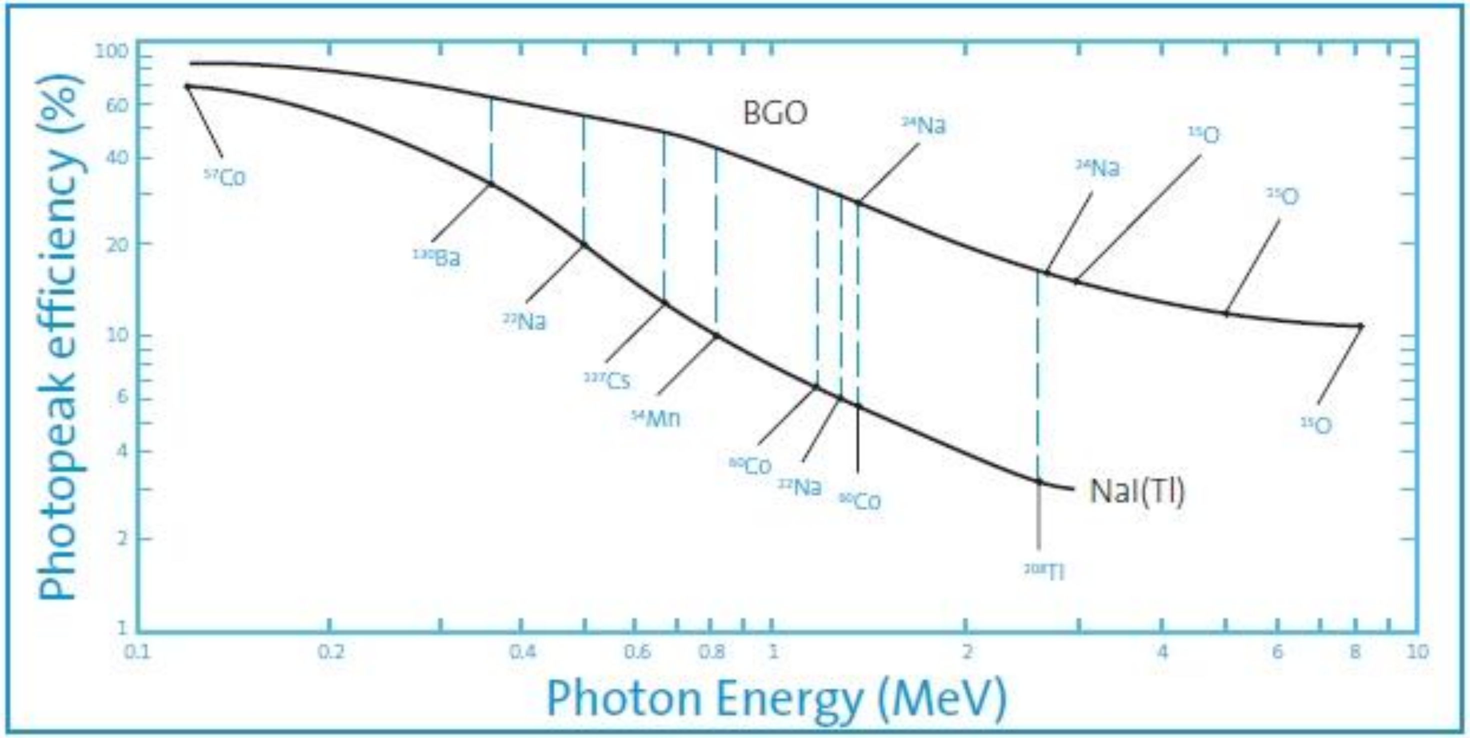


Figure 4. Photopeak efficiencies for BGO and NaI(Tl) scintillation detectors, 38mm diameter, 38 mm high.

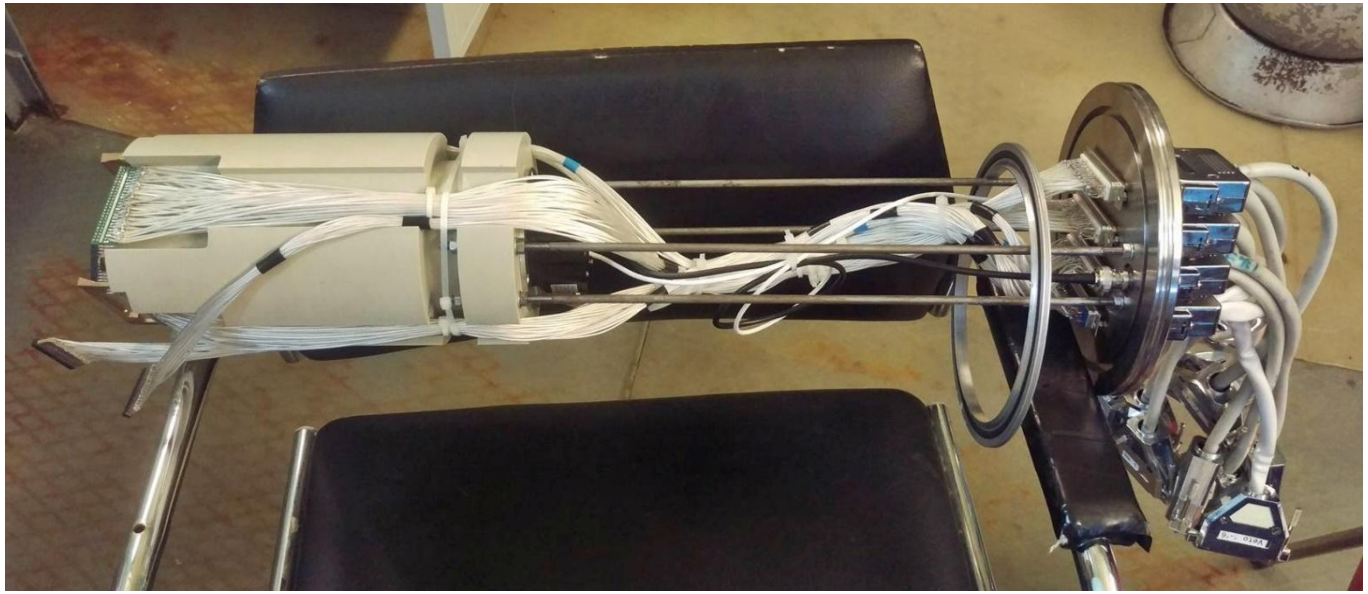
Silicon detector

Advantages of silicon:

- Reaction products are stopped in the detector
- α particle and fission fragments

are measured

- High energy resolution: ΔE = 40 keV, for α particles



Veto detector

For preparing the neutron detector we used a silicon detector as a trigger for neutrons.

Double-Sided Strip Detectors – CD Series

Features:

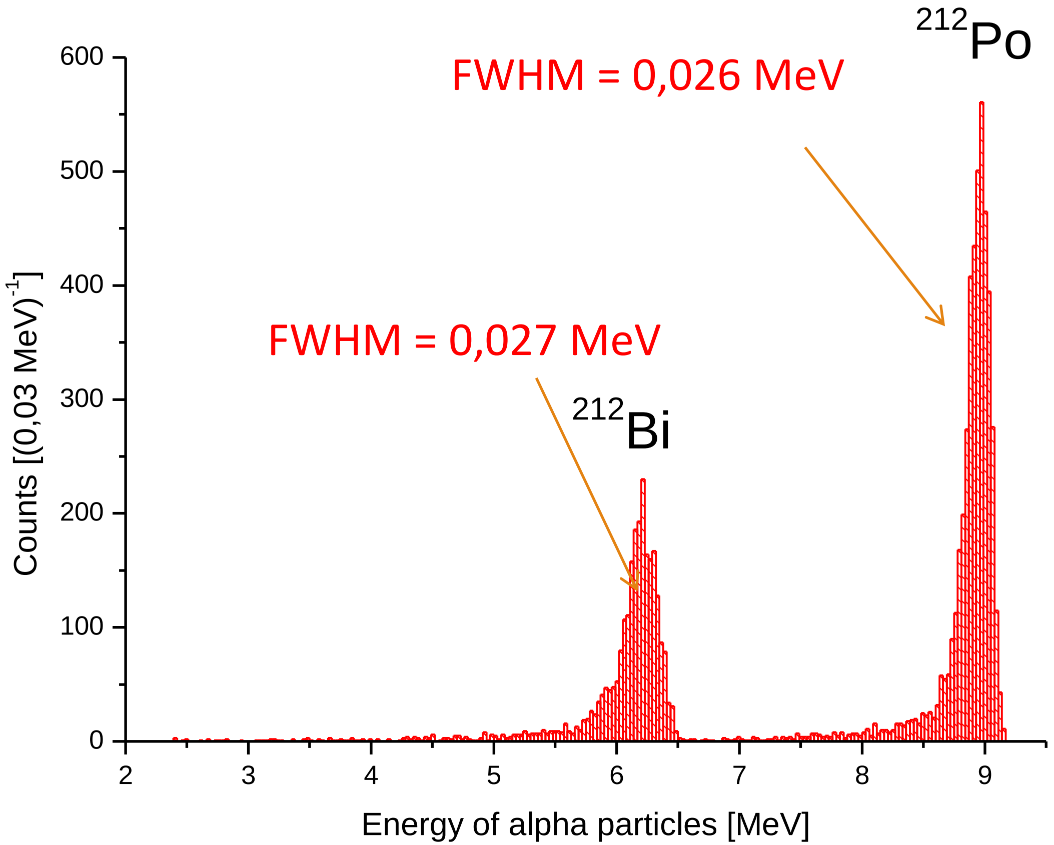
- Strip detectors mounted on epoxy boards
- Size: from 40 x 60 mm² and larger
- Active thickness: 300 to 400 µm

Advantages:

- Good timing performances

Calibration of detector

- ☐ We measured active emitters, which were placed in a vacuum.
- ☐ We evaluated the results of each sensor and then we evaluated best measured values for the center of the silicon detector.

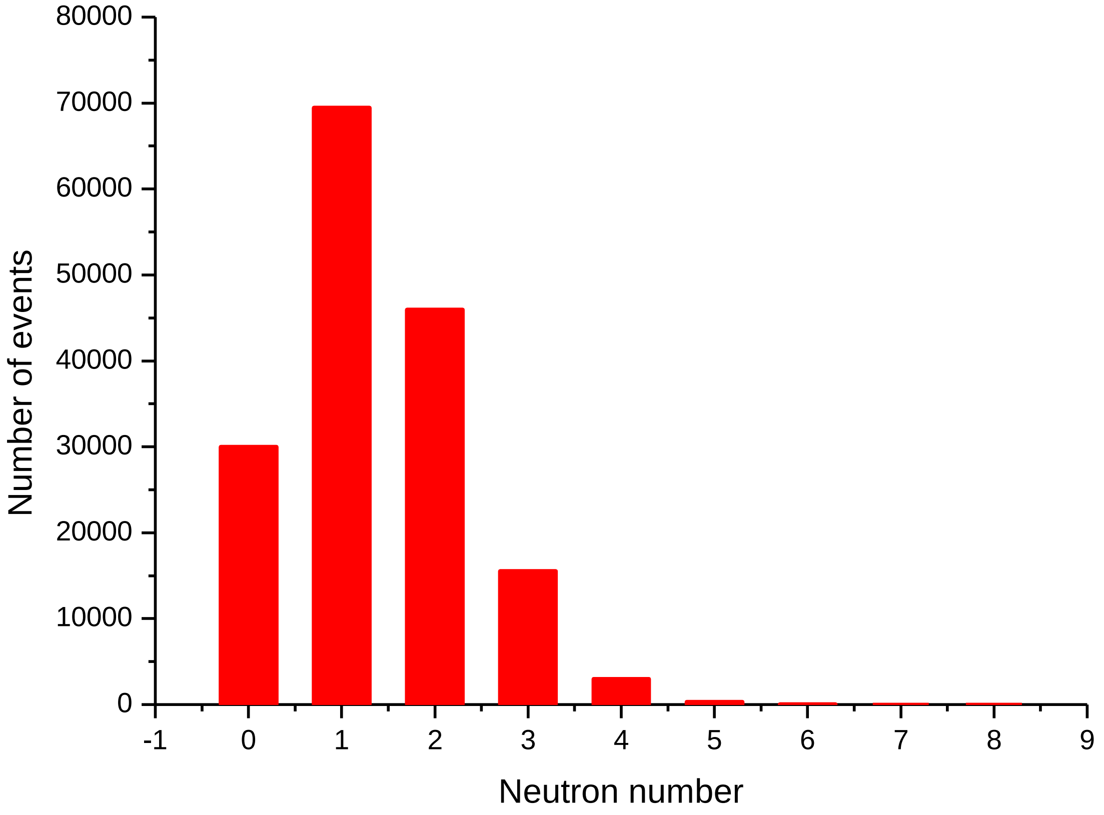


Goal of the experiment

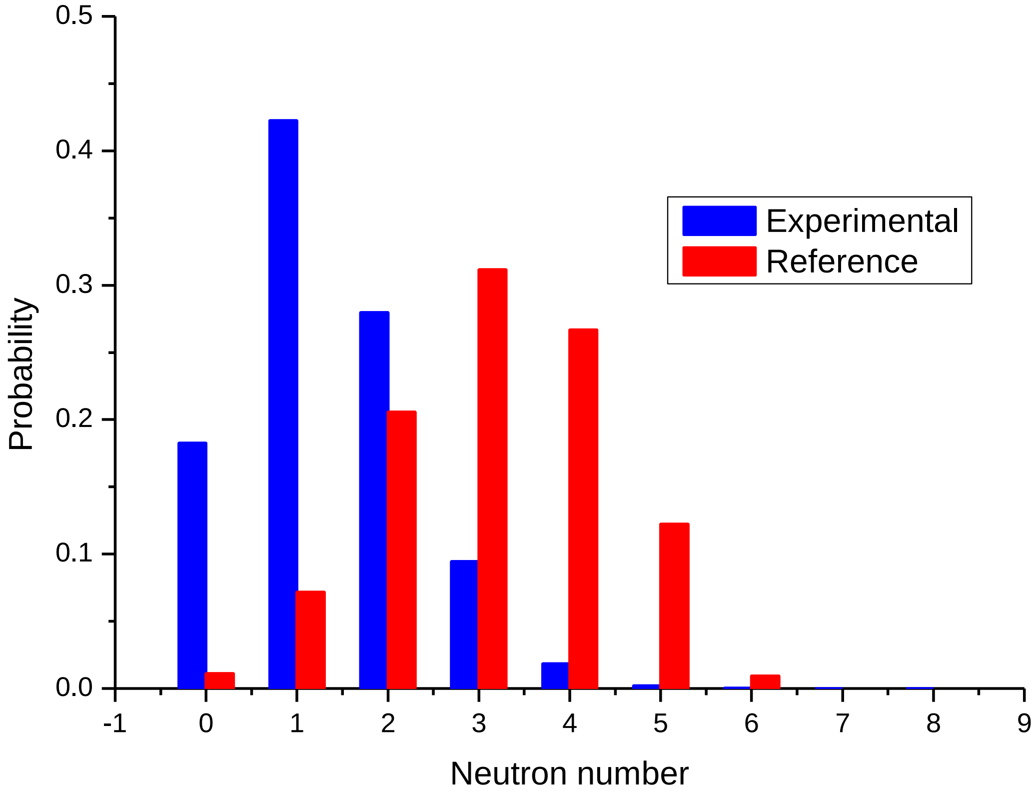
The main goal of our project was preparing the detection system of SHELLS setup for experiments aimed to investigation of neutron properties of spontaneous fissioning heavy nuclei.

- Calibration of Si detector with α sources
- Determing efficiency of neutron detector

Multiplicity and probability



The multiplicity distribution of emitted neutrons from spontaneous fission of ^{248}Cm



The experimental and reference probabillity distribution of emitted neutrons from spontaneous fission of ^{248}Cm

The efficiency of neutron detector

To determine the detector efficiency, we calculated some ratios between the numbers of emitted neutrons, and then we compared these ratios with some known ratios. We obtained different efficiency for each ratio, and then we calculated the average efficiency.

Number of neutrons	Ratio	Efficiency (%)	Average efficiency (%)
N_1=5412	N_1/N_2=1.14953	49	**46.8**
N_2=4708	N_1/N_3=2.7556	47	
N_3=1964	N_2/N_3=2.39715	46.5	
N_4=443	N_3/N_4=4.43341	46	
N_5=46	N_2/N_4=10.62754	45.5	

The efficiency of our detector when the ^{248}Cm source was placed at 0.2 cm away from the detector

We did the same measurements moving the ^{248}Cm source at 2 and 8 cm away from the detector, and the average efficiency we obtained was:

Distance (cm)	Average efficiency (%)
0.2 cm	46.8
2 cm	**45,7**
8 cm	**42,1**

We can observe that the efficiency drops when the distance grows, this means that not all the particles are detected, and the detector will detect more of the particles from the center of the beam.

Conclusion

- ❑ We collected a lot of data for spontaneous fission events (15000) and prompt neutrons emitted in this process (23000)
- ❑ We calibrated the Si detectors with alpha sources of known energies (^{212}Bi and ^{212}Po) from thorium decay chain:

  1 channel = 2,8 keV

  FWHM ($E\alpha_{Po212}$ - 8785 keV) = 26 keV (0.3%)
- ❑ The efficiency of neutron detector (Distance – 0.2 cm) was determined to be **46,8%**

Thank you for your attention !! ☺