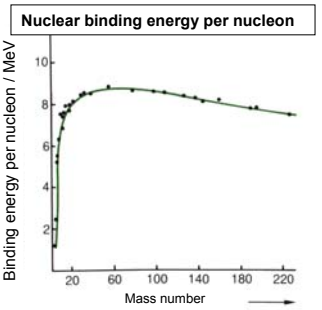
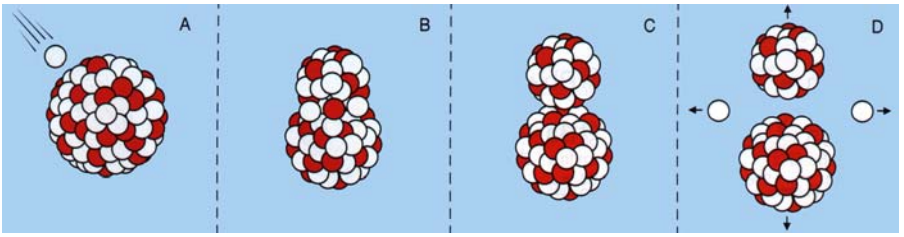
13) Nuclear fission (1)

Remind! Nuclear binding energy

- Sum of the masses of nucleons is bigger than the nucleus of an atom
- Difference: nuclear binding energy

- Energy can be gained by fusion of light elements or **fission of heavy elements**





13) Nuclear fission (2)

Spontaneous fission

- heavy nuclei are instable for spontaneous fission
- according to calculations this should be valid for all nuclei with A > 46 (Pd !!!!)
- practically, a high energy barrier prevents the lighter elements from fission

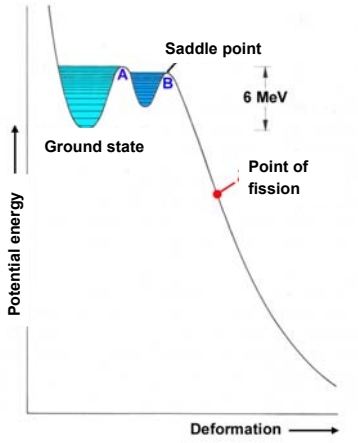
- spontaneous fission is observed for elements heavier than actinium
- partial half-lifes for ^{238}U: **$4{,}47 \times 10^9$ a (α-decay)**
  9×10^{15} a (spontaneous fission)

- Sponatenous fission of uranium is practically the only natural source for technetium
- contribution increases with very heavy elements (99% with ^{254}Cf)

13) Nuclear fission (3)

Potential energy of a nucleus as function of the deformation (A, B = energy barriers which represent fission barriers

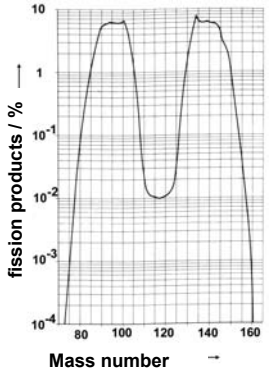
- transition state of a nucleus is determined by its deformation
- almost no deformation in the ground state
- fission barrier is higher by 6 MeV
- tunneling of the barrier at spontaneous fission

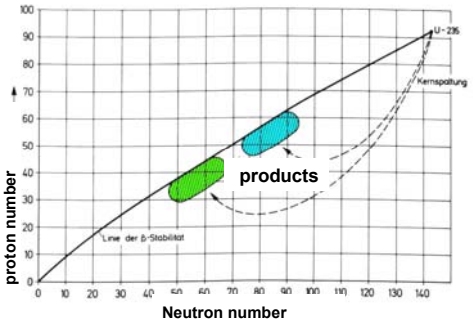


13) Nuclear fission (4)

Artificially initiated fission

- initiated by the bombardment with slow (thermal neutrons)
- as chain reaction discovered in 1938 by Hahn, Meitner and Strassmann
- intermediate is a strongly deformed „Compound“ nucleus
- asymmetric fission products are formed which are stabilised by subsequent ß- decays





13) Nuclear fission (5)

Energy / mass balance of a typical fission reaction

Reaction: $^{235}U \rightarrow {}^{140}Ce + {}^{94}Zr + 2\,n + 6\,\beta^-$

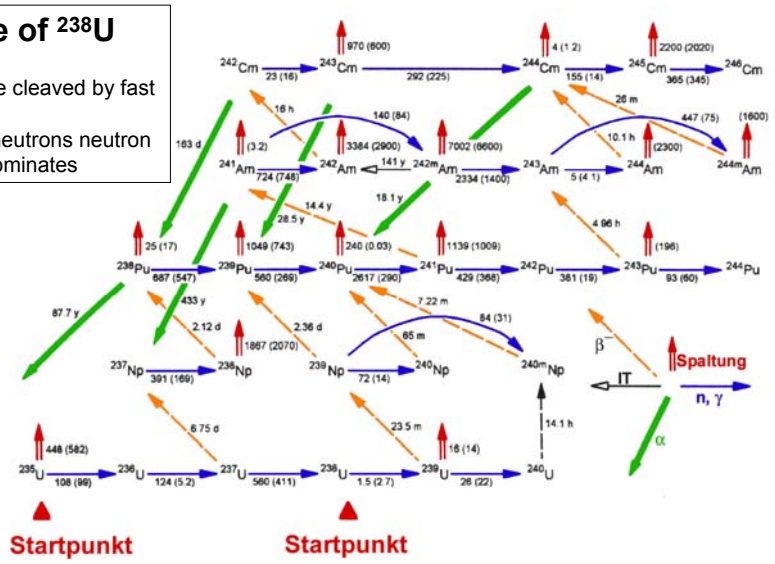
	Mass number A	absolute atom mass u
Original nucleus ^{235}U	235	235,0440
+ initiating neutron	1	1,0087
Sum before fission	**236**	**236,0527 u**
Formed nucleus ^{94}Zr	94	93,9063
Formed nucleus ^{140}Ce	140	139,9055
2 released neutrons	2	2,0174
6 released ß-partcles	-	0,0033
Sum after fission:	**236**	**235,8318 u**
		Δm = 0,2209 u ≃ 205 MeV

Kinetic energy of the fission products	165 MeV
Kinetic energy of the released neutrons	5 MeV
Primary gamma radiation	7 MeV
Gamma- and beta radiation of the fission products	13 MeV
Energy of neutrinos	10 MeV

13) Nuclear fission (6)

The role of ^{238}U

- can only be cleaved by fast neutrons
- with slow neutrons neutron capture dominates



13) Nuclear fission (7)

Nuclear Reactors

Different types of nuclear fuel

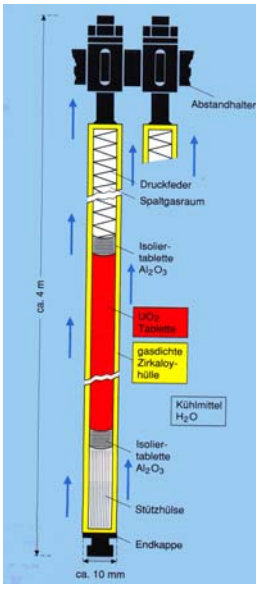
1) **Natural uranium**
   (0.72% ^{235}U, requires deuteriumoxide and graphite, energy mainly by the nuclear reaction of the formed ^{239}Pu)
2) **Slightly enriched uranium**
   (about 3% ^{235}U, use in power stations, pressurized-water reactors, boiling-water reactors, long-lived Pu isotopes are only formed in less than 1%)
3) **Highly enriched uranium**
   (>90% ^{235}U, practically exclusively in research reactors, marginal re-formation of nuclear fuel)
4) **Mixtures of uranium and plutonium**
   (breeders, mainly fission of ^{239}Pu gives energy, depleated uranium is used)
5) **Mixtures of uranium and thorium**
   high-temperature reactors, ^{232}Th is converted into ^{233}U, which is used as nuclear fuel)

13) Nuclear fission (8)

Nuclear Reactors

Vessel of a pressurized-water reactor

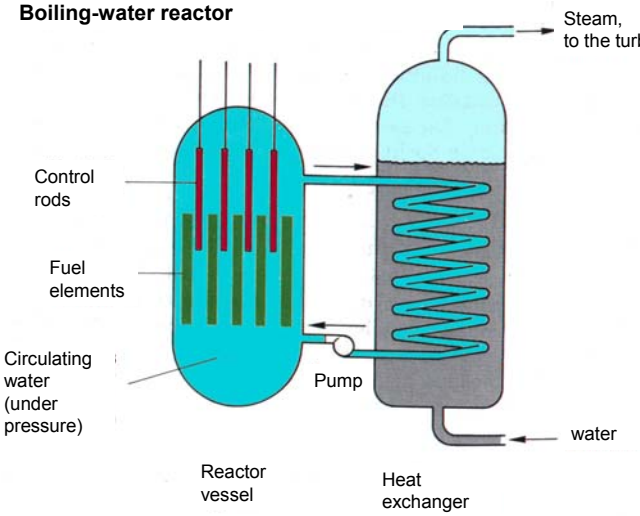
Fuel element



13) Nuclear fission (9)

Nuclear Reactors

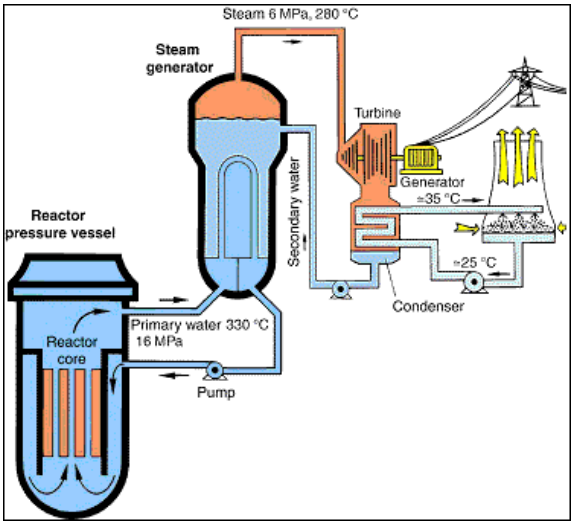
Boiling-water reactor



13) Nuclear fission (10)

Nuclear Reactors

Pressurized-water reactor



Nuclear Reactors

Nuclear power station Brokdorf (Germany)