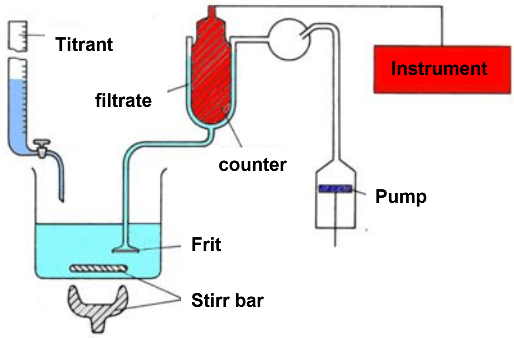
7) Applications of Nuclear Radiation in Science and Technique (1)

Analytical applications
(Radiometric titration)

The radioactive material is indicator

- Precipitation reactions
- Complex formation reactions

Principle of a precipitation titration:



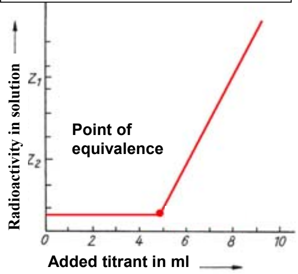
7) Applications of Nuclear Radiation in Science and Technique (2)

Analytical applications
(Radiometric titration)

Typ I

Titration of a non-radioactive substance with a radioactive titrant

AC + ***B**C → A***B** + CD

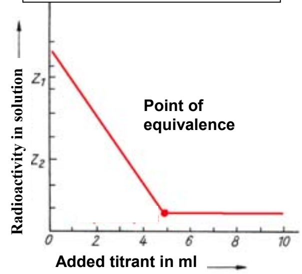


Example:
NaCl + $^{110m}AgNO_3$ → $^{110m}AgCl$ ↓ + $NaNO_3$

Typ II

Titration of a radioactive substance with a non-radioactive titrant

***A**C + BC → ***A**B + CD

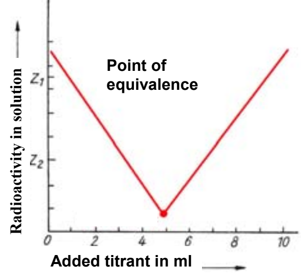


Example:
$^{110m}AgNO_3$ + HCl → $^{110m}AgCl$ ↓ + HNO_3

Typ III

Titration of a radioactive substance with a radioactive titrant

A**C + ***B**C → ***A**B** + CD

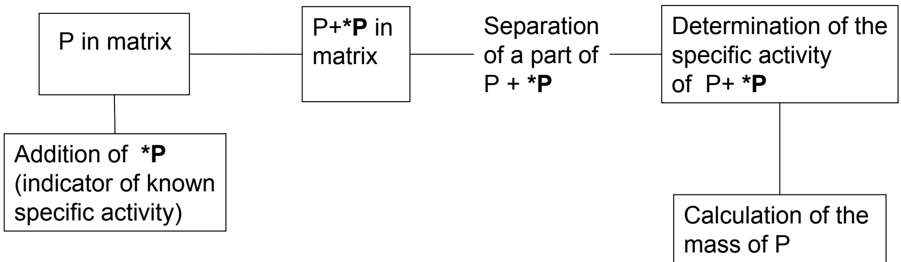


Example:
$Na^{131}I$ + $^{110m}AgNO_3$ → $^{110m}Ag^{131}I$ ↓ + $NaNO_3$

7) Applications of Nuclear Radiation in Science and Technique (3)

Analytical applications
(Isotope dilution analysis)

- Changes in the specific activity of an indicator substance (*P) are measured after adding it to an unknow (but chemically indentical) quantity of the substance
- quantitative separation of the unknown substance is not required to determine its quantity

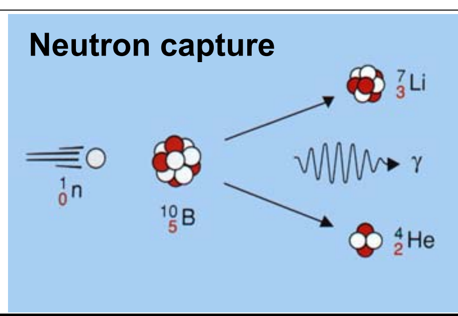


Applications:
- Doping analytics
- Biochemical and pharmaceutical research
- Determination of the blood-volume in medicine

7) Applications of Nuclear Radiation in Science and Technique (4)

Analytical applications
(Neutron activation analysis)

Principle:
- highly sensitive elemental analysis
- generation of (a few) radioactive atoms of a specific element inside a non-radioactive sample by bombardment with slow neutrons
- measurement of the radioactivity of the induced radioactivity
- the intensity of the radioactivity is representative to the content of the (activated) element
- depending on the supplied neutron flux (nuclear reactor or neutron source) almost all chemical elements can be studied with this method



7) Applications of Nuclear Radiation in Science and Technique (5)

Analytical applications
(Neutron activation analysis)

Advantages:

- non-destructive with samples up to some cm^3
- Sample and standard can contain the element in different chemical forms
- high sensitivity

Disadvantages:

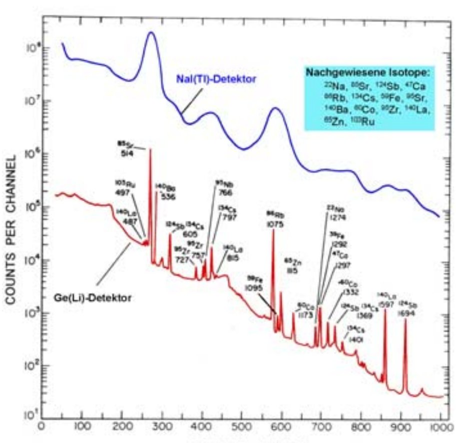
- expensive (neutron source or nuclear reactor is required)
- Radiation protection and (partially) waste treatment
- undesired activation of neighbouring elements when activating with thermal neutrons

Application in :
- **geology, mining, cosmology** (huge amounts of samples, multi-element analysis, high accuracy)
- **environmental protection** (large amount of samples, high sensitivity)
- **material science** (various samples, medium accuracy)

7) Applications of Nuclear Radiation in Science and Technique (6)

Analytical applications (Neutron activation analysis)

Application of NAA for the detection of trace amounts of metals in sea water



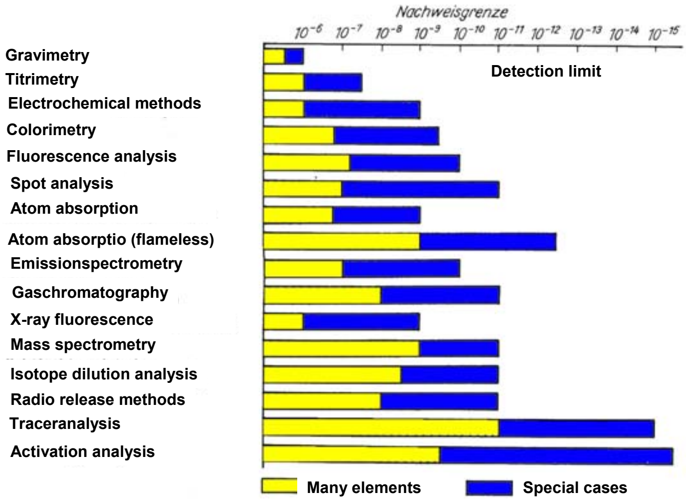
Detection limits of NAA for 71 elements:

Detection limit in µg	Elements
10 – 30	Si, S, Fe
1 – 4 x 10^{-1}	F, Ne, Ca, Cr, Zr, Tb
4 – 9 x 10^{-2}	K, Ni, Rb
1 – 3 x 10^{-2}	Cl, Ti, Zn, Se, Sn, Ce, Ta, Th
4 – 9 x 10^{-3}	Ar, Mo, Pr, Gd
1 – 3 x 10^{-3}	Co, Ge, Nb, Ru, Cd, Sb, Te, Xe, Nd, Yb, Pt, Hg
4 – 9 x 10^{-4}	Na, Al, Cu, Ga, As, Sr, Pd, I, La, Er
1 – 3 x 10^{-4}	Sc, Br, Y, Ba, W, Re, Os, U
4 – 9 x 10^{-5}	V, Ag, Cs, Sm, Hf, Ir, Au
1 – 3- x 10^{-5}	Kr, Rh, In, Eu, Ho, Lu
4 – 9 x 10^{-6}	Mn
1 – 3 x 10^{-6}	Dy

7) Applications of Nuclear Radiation in Science and Technique (7)

Analytical applications
(Neutron activation analysis)

Radioanalytical methods compared with conventional techniques



7) Applications of Nuclear Radiation in Science and Technique (8)

Analytical applications (Dating with radiometric methods)

Radiocarbon Method

- **Dating of archeological samples in the range of about 250 - 40 000 years**
- The ^{14}C which is form by cosmic radiation ist readily oxidized to CO_2
- CO_2 is incorporated into the process of assimilation into plants
- distribution via food into animal and man
- with the death of the organisms the ^{14}C uptake ends
- The older an archeological sample is the less is its ^{14}C content
- a number of corrections have to be applied to give accurate data

^{14}C:

Formation $^{14}_{7}N + ^{1}_{0}n \rightarrow ^{14}_{6}C + ^{1}_{1}p$

Decay $^{14}_{6}C \rightarrow ^{14}_{7}N + ^{0}_{-1}e$

$T_{1/2} = 5730$ a

Other cosmogenic radionuclides which can be applied in a similar way:

Nuclide	Half life	Range of Dating
^{3}H	12.3 y	0.5 - 80 y
^{10}B	1.6×10^{6} y	$10^{4} – 10^{7}$ y
^{26}Al	7×10^{5} y	$10^{5} – 10^{6}$ y
^{39}Ar	269 y	$10^{2} – 10^{4}$ y

7) Applications of Nuclear Radiation in Science and Technique (9)

Analytical applications
(Dating with radiometric methods)

Terrestrial Mother/daughter nuclide pairs

Application of the ^{40}K Decay

$$^{40}_{19}K \rightarrow ^{40}_{18}Ar$$

The formed argon is released when the mineral is dissolved

Determination of the Ar content

Determination of the K/Ar ratio

Examples

Oldest terrestrial minerals: $3,7 \times 10^9$ a

Moon minerals (meteorits): $4,6 \times 10^9$ a

Age of the sun system: ca. $4,6 \times 10^9$ Jahre

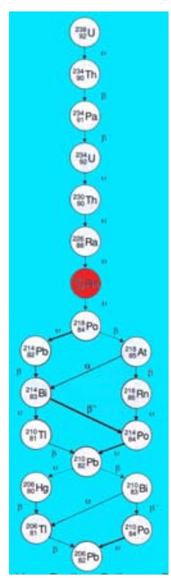
Other mother/daugter pairs which can be applied in a similar way:

Pair	Half life of the mother	Range of dating
$^{87}Rb/^{87}Sr$	1.28×10^9 y	$10^3 - 10^{10}$ y
$^{147}Sm/^{143}Nd$	4.8×10^{10} y	$8 \times 10^6 - 10^9$ y
$^{176}Lu/^{176}Hf$	3.8×10^{10} y	$10^7 - 10^{10}$ y
$^{187}Re/^{187}Os$	5×10^{10} y	$10^6 - 10^{10}$ y

7) Applications of Nuclear Radiation in Science and Technique (10)

Analytical applications
(Dating with radiometric methods)

Decay series



Application of the $^{238}_{92}U \rightarrow ^{206}_{82}Pb$ **decay series**

The longest half-life in this series is that of $^{238}_{92}U$ ($4,468 \times 10^9$ a)

^{238}U decay determines the rate of the radioactive decay in the series

geological dating is possible applying the $^{238}U/^{206}Pb$ ratio

Requirements: - „closed system“ for the radioactive decay (no member of the series is allowed to escape, Rn is a gas!!)

- is given for the crystal lattices of minerals