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Uranium

Uranium is a heavy metal, whose isotopes all are radioactive. For humans it is much more harmful because of its toxicity than because of its radioactivity. Usually, only the total amount of uranium in a water sample is analyzed and not its isotopic composition. However, the uranium isotopes analysis can enable a determination of the age of very old groundwaters and furthermore it is used for a detailed investigation of the total indicative dose. The age determination is very complex because it needs a lot of details about the boundary conditions. For this reason it is not a common investigation.

Uranium occurs naturally in many rock formations (especially in the continental crust) and for this reason also in groundwater and, surface waters, respectively. In Germany, a limiting value of 10 µg/l for uranium in drinking water was specified. The uranium concentration in water is dependent on the surrounding rocks with which the water was in contact. Because the dissolution conditions of uranium into water are relatively complex, a high content of uranium in the rocks not necessary induce high uranium concentration in the water. The mobility of uranium is influenced by the oxidation potential and the carbon alkalinity of the fluid as CO_3^{2-} forms complexes with the highly soluble uranyl (UO_2^{2+}). The mean uranium content of some rock formations and common water types are listed in table 1.

Table 1: The mean uranium content of some common rock formations and water types.

Rock type	**Uranium content (µg/g)**
Granite	2,2 - 6,1
Lime stone	ca. 2
Sand- und Clay minerals	0,7 – 4
Coal	10 – 6000
Water type	**Uranium content (µg/l)**
Groundwaterr	0,01-10
Large rivers	0,8 – 10
Ocean	3,3

Anthropogenic sources of uranium are primarily uranium containing phosphate fertilizers, burning of coal and oil, seepage water from mines, waste dumps and sedimentation installations.

The three most important naturally occurring uranium isotopes are:

uranium-234 half life-time: $2{,}455 \times 10^5$ y

uranium-235 half life-time: $7{,}038 \times 10^8$ y

uranium-238 half life-time: $4{,}468 \times 10^9$ y

With an abundance of 99.3%, uranium-238 the most frequent uranium isotope. While uranium-234 is naturally occurring only in traces, uranium-235 are the residual 0.7% of the uranium isotopes.

Uranium-238 is the mother-isotope of a so called uranium-238 decay chain. This chain consists of the mother-isotope uranium-238, which decays via 13 daughter-isotopes to the finally stable daughter-isotope polonium-206. For an illustration of this decay chain see figure 1. The decay chains of uranium-235 and thorium-232 are not showed here, but have to be taken in account in case of an interpretation of isotope analysis.

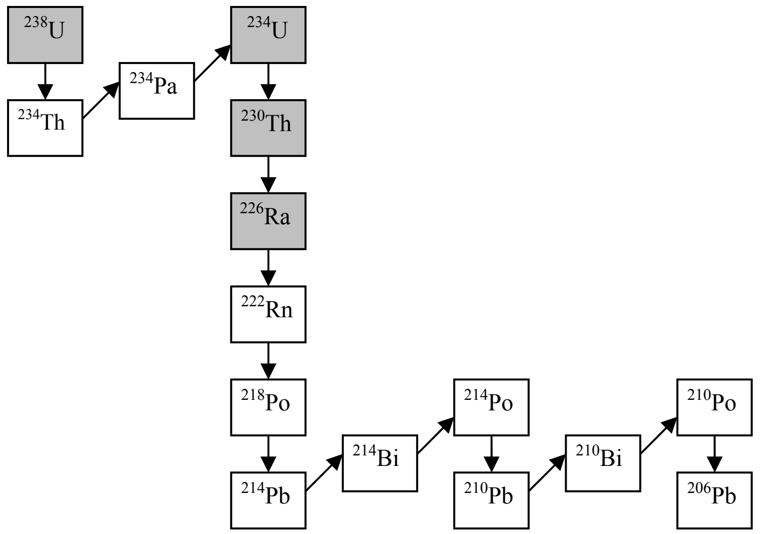

Figure 1: Decay chain of uranium-238. An arrow pointing down means α-decay. The arrows pointing to top right represent β-decay. The isotopes in uncoloured boxes are short-lived isotopes, i.e. they decay rapidly (half-life of some seconds up to a few years).

In hydrogeology for the age determination especially the activity ratio of uranium-234 to uranium-238 is considered. Both isotopes are part of the decay chain of uranium-238 (s. figure 1). They enable an age determination of groundwater up to several tens of thousands years, whereas the data interpretation prerequisites an extensive knowledge about boundary conditions and careful analysis by experts.

The activity ratio from isotopes within the same decay series approximates to 1, if a long time period is considered (secondary equilibrium) and if the treated system can be considered as closed. However, an activity ratio of 1 does not imply a concentration ratio of 1. Hence, the different solubilities of the daughter isotopes, depending on the present redox-conditions, lead to disequilibria and sorting processes of the elements in the decay series.

Considering the influences on the concentration ratios between uranium-234 and uranium-238, these sorting processes of the elements are much more important than isotope fractionation processes.

Due to the ambiguous determination of the boundary conditions, the interpretation of the uranium isotope analysis regarding an age determination is not trivial and entails uncertainties.

Both, the determination of the total uranium concentration in a water sample and the isotope analysis, are performed through ICP-MS (Inductively coupled plasma mass spectrometer).