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Activities and activity ratios of U and Ra radioisotopes in drinking wells, springs and tap water samples in Morocco

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Summary. Radiochemical results (^{234}U, ^{238}U, ^{226}Ra and ^{228}Ra activities; $^{234}U/^{238}U$, $^{226}Ra/^{238}Ra$ and $^{228}Ra/^{238}U$ activity ratios) are reported for 31 drinking water samples collected from 8 wells, 12 hot mineral springs, 5 cold springs, and 6 tap water samples. Activities of the Ra isotopes were measured by gamma spectrometry using a low background and high efficiency well type germanium detector. The U isotopes were counted in an alpha spectrometer. The results show that ^{238}U activity varies between 4.46 and about 308 mBq l^{-1} in wells, 0.59 and 17.88 mBq l^{-1} in hot springs, 2.19 and 3.21 mBq l^{-1} in cold springs, and between 2.5 and 15.70 mBq l^{-1} in tap water samples. $^{234}U/^{238}U$ activity ratio is generally higher than 1 which is the equilibrium activity ratio value in closed systems. It varies in the ranges 0.79–2.11 in wells, 0.97–7.39 in hot springs, 2.53–8.30 in cold springs, and 1.14–3.35 in tap water. Unlike well waters, spring waters show low ^{238}U activities and high $^{234}U/^{238}U$ activity ratios. The highest activity of Ra measured in hot mineral water samples is about 150 and 352 times higher than the highest activity of Ra found in well waters and in cold springs, respectively. $^{226}Ra/^{238}U$ activity ratios are in the ranges: 0.07–1.14 in wells, 1.79–2115 in hot springs, 0.86–4.79 in cold springs, and 0.18–5.61 in tap water samples. The data are similar to those published for other regions of the world.

1. Introduction

The presence and behaviour of radioelements in natural waters from different sources have been widely studied throughout the world [1–16]. The behaviour of U and Th decay series nuclides in ground water is of interest to geochemists, U explorations, and health physicists. Studies of ^{238}U series nuclides in ground water have had a variety of purposes including the calculation of metal scavenging rates [13], developing U exploration models [3], and the assessment of the effects of phosphate mining on water quality [17, 18]. On the other hand, ^{226}Ra has been used as a tracer of large-scale ocean circulation processes and observed increase of ^{226}Ra with depth in the ocean reflects the effects of biological cycling on the ocean surface together with the bottom source function [19]. Other studies concerning Ra concentration in riverine [20] and estuarine environments [21] allow one to understand the Ra redistribution in the environment and the resulting health consequences.

The natural radioactivity in wells and spring waters comes mainly from the primordial radionuclides in soils (^{40}K and the 4n and 4n+2 series). Furthermore, some cosmogenic radionuclides and/or radionuclides originating from a pollution can be found in natural waters used for drinking. The cosmogenic nuclides, like ^{3}H and ^{7}Be, have been added to these waters through rain water. The natural polluting radioelements can arise from industrial wastes, geological erosion of U-bearing rocks or excessive utilization of agricultural fertilizers. Concentrations of natural radioelements in water depend on the physico-chemical conditions and on the geological, geographical and socio-economical environment.

The natural radioactivity of groundwater varies greatly. High concentrations of natural radioactive elements have been found not only in water from U mines, but also in mineral water and in some drilled wells [2, 4, 16]. The knowledge of U and Ra concentrations in drinking water is important because an appreciable fraction of the absorbed U and Ra is deposited in human bone, with the corresponding contribution to the internal dose.

In this work, we have applied for the first time in Morocco, a rapid combined technique for measuring U and Ra isotopes from the same water sample. Some results obtained from drinking water samples collected from different sites (springs, wells and tap water) will allow us to compare U and Ra activities at these sites and help us to orient the next samplings in order to establish a distribution map of the radioelements in natural drinking waters of Morocco. A comparison between activities of U and Ra isotopes in drinking water samples taken from different localities in Morocco could also help us to know whether radioactivity had a polluting or natural origin.

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2. Sampling and methods

2.1 Sampling

The analyzed natural water samples have been collected from 8 wells, 12 hot springs and 5 cold springs. Tap water samples from 5 distant cities have been analyzed as well. The sampled sites have been chosen at different locations in Morocco in order to give significant preliminary results which could orient next samplings. The region of *Fez* is characterized by an important presence of hot mineral springs. Water of some of these sources is commercialized (*Sidi Harazem*) or used as water of bath to heal some skin sicknesses because of its wealth in mineral salts (*Ain Allah, My Yacoub*). *Khouribga* region is located in the interior of the country on the largest tray of phosphates in Morocco. It is often affected by dryness which explains the high number of drilled wells in this region. Sample No. 22 has been taken from a well located at about one km from one of the phosphate extraction sites to the east of the city of Khouribga.

2.2 Sample preparation

Twenty litres of water are collected in a polyethylene tank and immediately acidified to pH 2–3 with concentrated HNO_3. After filtration, iron carrier ($FeCl_3$) (50–80 mg) and known $^{232}U/^{229}Th$ equilibrated spike solution are added. U and Th are coprecipitated with $Fe(OH)_3$ by addition of NH_4OH to pH 8 to 9 as described by Choukri [22]. A known quantity of barium in $BaCl_2$ form (1 g) is then added. Ra isotopes are coprecipitated with $BaSO_4$ (weight corrected by a mass factor of 1.16 due to the conversion of $BaCl_2$ to $BaSO_4$) formed by addition of H_2SO_4 drops in the medium without significant changing of pH. Precipitation of hydroxides is achieved before the Ba and H_2SO_4 addition step to avoid coprecipitation of Th with H_2SO_4. The two precipitates are recovered by filtration and rinsed on the filter with deionized water. The filtrates were obtained before adding spikes and after hydroxides and $BaSO_4$ precipitation using a 0.4 µm filter pore size. The first filtration allows to remove the suspended matter, but no suspended matter has been observed in all analyzed water samples. The good recoveries for U and Th separation (40 to 70% including all separation and extraction steps), and for Ra extraction (70 to 100%) show that hydroxides and $BaSO_4$ filtration efficiency was quantitative.

The recovered precipitates on the filter are recuperated into a polyethylene tube and 8 N HNO_3 is then added. Hydroxides containing U and Th are soluble in acid medium whereas $BaSO_4$ coprecipitated with Ra is not soluble in this medium. The two fractions are separated by filtration or centrifugation. The insoluble $BaSO_4$ is rinsed with 8 N HNO_3, then with deionized water.

2.3 Separation and activity measurement of U and Th Isotopes

Complete mixing and oxidation are achieved by evaporating to dryness the solution containing U and Th, obtained by dissolution of hydroxides in acid medium. The dry residue is dissolved in 8 N HCl and the hydroxides are precipitated at pH 8 to 9 with ammonium hydroxide. In this step, Th and U are precipitated together with iron hydroxides, aluminium and other impurities. After dissolution in 8 N HCl, the sample is filtered and is ready for the ion exchange procedure (Fig. 1).

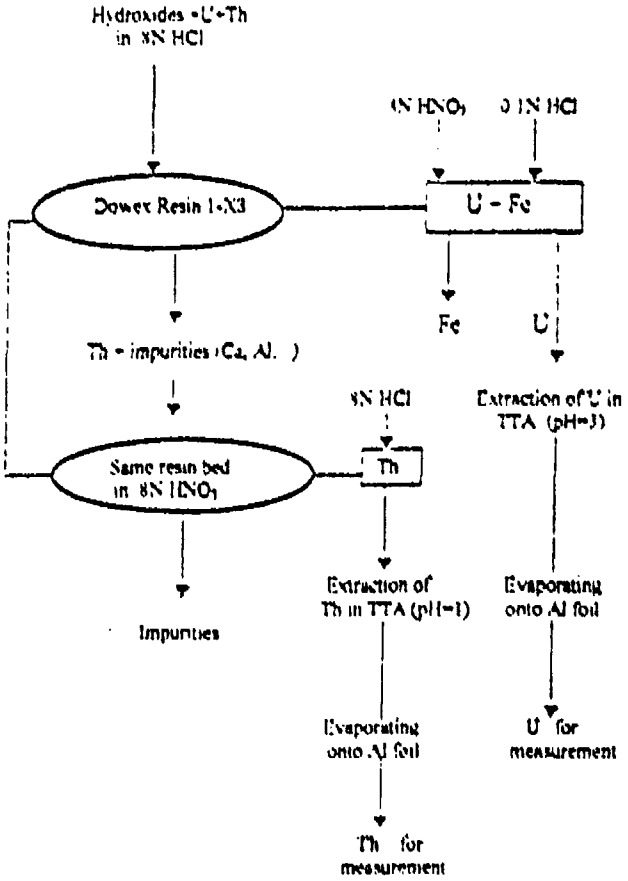

Fig. 1. Separation scheme for U and Th in water samples by ion-exchange resin.

Table 1. Energies and intensities of daughters used to measure ^{226}Ra and ^{228}Ra activities.

	Isotope	Energy (keV)	Intensity (%)
^{226}Ra	^{226}Ra	185.9	3.28
	^{214}Pb	241.9	7.47
	^{214}Pb	295.2	19.20
	^{214}Pb	352.0	37.10
	^{214}Bi	609.3	46.09
^{228}Ra	^{228}Ac	338.5	12.01
	^{228}Ac	964.9	5.5
	^{228}Ac	968.9	17.46

A single resin exchange column is used twice: (1) In the first step, U and Fe are fixed on the resin in a 8 N HCl medium while Th and other impurities are collected with the effluent. Fe is then eluted with 15 ml of 8 N HNO_3. U is eluted with 30 ml of 0.1 N HCl and evaporated to dryness, and (2) In the second step, Th is loaded on the resin bed in 30 to 40 ml of HNO_3 to ensure solely the fixation of Th. The latter is eluted with 8 N HCl and evaporated to dryness. The ion exchange procedure is identical to that

Table 2. ^{234}U, ^{238}U, ^{226}Ra and ^{228}Ra activities in analyzed samples.

n°	Site	Location	^{234}U (mBq l^{-1})	^{238}U (mBq l^{-1})	^{226}Ra (mBq l^{-1})	^{228}Ra (mBq l^{-1})
Hot springs						
1	Sidi Harazem[a] (s)	Fez	39.02 ± 3.24	6.05 ± 0.72	51.90 ± 1.30	9.10 ± 1.10
2	Sidi Harazem[b] (s)	Fez	38.50 ± 3.53	5.21 ± 0.61	60.40 ± 1.60	11.40 ± 1.40
3	Sidi Harazem (c)	Fez	36.02 ± 2.56	5.19 ± 0.52	89.10 ± 1.20	16.20 ± 1.10
4	Ain Allah[a]	Fez	25.70 ± 2.34	5.40 ± 0.58	30.00 ± 0.60	3.10 ± 0.10
5	Ain Allah[b]	Fez	26.64 ± 2.47	8.51 ± 1.05	29.80 ± 0.60	2.40 ± 0.40
6	My Yacoub	Fez	11.87 ± 1.08	6.45 ± 0.75	3696 ± 12	920 ± 10
7	Oulmes (c)	Oulmes	2.44 ± 0.27	0.59 ± 0.09	1248 ± 3	96.50 ± 1.30
8	Sidi Ali (c)	Oulmes	4.92 ± 0.74	5.07 ± 0.76	9.10 ± 0.60	3.30 ± 0.60
9	Ouled Regua	F.B. Salah	41.12 ± 2.29	17.58 ± 1.17	122.00 ± 2.10	9.80 ± 1.60
10	My Hachem	Errachidia	49.43 ± 4.17	13.73 ± 1.80		
11	My Ali	Errachidia	3.61 ± 0.59	3.01 ± 0.31		
12	Bleu Meski	Errachidia	47.12 ± 4.08	15.55 ± 1.89		
Cold springs						
13	Foum el Anser	Beni Mellal	10.62 ± 1.20	2.19 ± 0.36	10.50 ± 0.47	3.30 ± 0.60
14	Ain Asserdoun	Beni Mellal	15.13 ± 1.23	2.85 ± 0.32	2.45 ± 0.25	0.75 ± 0.19
15	Tirhboula	Beni Mellal	22.41 ± 1.37	2.70 ± 0.24	9.05 ± 0.49	2.40 ± 0.50
16	Charmou	Azrou	8.12 ± 1.11	3.21 ± 0.50		
17	Kharzouza	Azrou	7.29 ± 0.53	2.23 ± 0.25		
Wells						
18	Settat	Settat	166.45 ± 27.10	164.80 ± 26.80	10.83 ± 0.50	17.26 ± 1.26
19	Beni Yakhlef	Khouribga	4.37 ± 0.28	4.46 ± 0.32	5.10 ± 0.30	1.00 ± 0.20
20	Ourghida	Khouribga	24.33 ± 1.98	22.53 ± 1.84	25.00 ± 1.00	5 ± 1
21	Lahmma	Khouribga	30.39 ± 2.27	26.20 ± 1.98	15.10 ± 1.40	0.60 ± 0.40
22	1 km Phos. extr.	Khouribga	243 ± 22	308.43 ± 27.53		
23	Beni Mellal	Beni Mellal	13.19 ± 0.99	6.25 ± 0.53	1.00 ± 0.20	1.20 ± 0.30
24	Ouled Regua	F.B. Salah	61.21 ± 4.17	60.60 ± 4.13	6.31 ± 0.32	4.80 ± 0.50
25	Beni Amir	F.B. Salah	44.12 ± 3.64	45.48 ± 3.75	5.42 ± 0.38	4.90 ± 0.60
Tap water						
26	Kenitra	Kenitra	2.85 ± 0.32	2.50 ± 0.30	0.46 ± 0.06	0.77 ± 0.04
27	Khouribga	Khouribga	21.67 ± 1.90	15.70 ± 1.41	34.60 ± 1.50	7.70 ± 1.40
28	K. Tadla	K. Tadla	15.06 ± 1.06	7.24 ± 0.56	40.60 ± 1.70	5.40 ± 2.20
29	F.B. Salah	F.B. Salah	24.68 ± 1.76	12.92 ± 0.98	45.80 ± 0.90	12.40 ± 1.00
30	Beni Mellal	Beni Mellal	12.80 ± 1.67	8.31 ± 1.24	2.12 ± 0.29	<0.40
31	Errachidia	Errachidia	34.07 ± 3.52	10.17 ± 1.40		

(s): water from spring. a: first sampling.
(c): commercialized mineral water. b: second sampling.

used in [23, 24] for U and Th separation in carbonate samples with minor modifications. It is shown in Fig. 1.

After these anionic exchange steps, Th is ready for deposition while U must be separated from residual iron. Its purification is performed by diisopropyl ether extraction, followed by evaporation of the aqueous fraction containing U.

In the last step, U and Th are extracted separately with TTA (1-(2-thenoyl)-3,3,3-trifluoroacetone) in toluene in a nitric media at pH 3 and 1, respectively. The two organic phases containing U and Th are evaporated onto aluminium foils and flamed to remove any trace of carbon. The thin sources are, at the end, ready for alpha spectrometry.

2.4 Determination of Ra

Ra is extracted from the water samples by precipitation with $BaSO_4$ after removal of U and Th as described above. Schmidt and Reyss [25] reported that this method is essentially quantitative for Ra removal. The (Ba-$RaSO_4$) is dried at room temperature. The obtained powder is sealed into a plastic ferrule whose form is compatible with the dimensions of the used well type Germanium detector. The gamma spectrum is measured after 20 days which is necessary to ensure radioactive equilibrium between Ra isotopes and their daughters. The efficiency of Ra extraction by $BaSO_4$ precipitation is obtained by calculating the ratio of the weight of recovered $BaSO_4$ to that of added $BaCl_2$ (corrected by a mass factor of 1.16). Extraction efficiencies are, in most cases, in the range 75–100%. Ra activity is measured by gamma spectrometry using a 220 cm^3 low-background well type gamma ray detector in the Laboratoire Souterrain de Modane (LSM-Centre National de la Recherche Scientifique (CNRS-France)/Commissariat à l'Energie Atomique. ^{226}Ra and ^{228}Ra activities are measured from gamma rays as mentioned in Table 1.

3. Results

The activities of U isotopes (^{234}U, ^{238}U) and Ra isotopes (^{226}Ra, ^{228}Ra), for the analyzed samples, are given in Ta-

Table 3. $^{234}U/^{238}U$, $^{228}Ra/^{226}Ra$ and $^{226}Ra/^{238}U$ activity ratios in analyzed samples.

n°	$^{234}U/^{238}U$	$^{228}Ra/^{226}Ra$	$^{226}Ra/^{238}U$
Hot springs			
1	6.45 ± 0.53	0.18 ± 0.02	8.58 ± 1.04
2	7.39 ± 0.62	0.19 ± 0.02	11.59 ± 1.39
3	6.94 ± 0.56	0.18 ± 0.01	17.17 ± 1.73
4	4.76 ± 0.32	0.103 ± 0.004	5.56 ± 0.61
5	3.13 ± 0.26	0.09 ± 0.01	3.15 ± 0.39
6	1.84 ± 0.25	0.168 ± 0.003	573 ± 66
7	4.13 ± 0.74	0.050 ± 0.001	2115 ± 321
8	0.97 ± 0.15	0.06 ± 0.01	1.79 ± 0.29
9	2.30 ± 0.12	0.08 ± 0.01	6.82 ± 0.46
10	3.60 ± 0.48		
11	2.86 ± 0.31		
12	3.03 ± 0.35		
Cold springs			
13	4.85 ± 0.72	0.31 ± 0.06	4.79 ± 0.81
14	5.31 ± 0.51	0.31 ± 0.08	0.86 ± 0.13
15	8.30 ± 0.62	0.27 ± 0.06	3.35 ± 0.35
16	2.53 ± 0.43		
17	3.27 ± 0.44		
Wells			
18	1.01 ± 0.04	1.59 ± 0.14	0.07 ± 0.01
19	0.98 ± 0.12	0.20 ± 0.04	1.14 ± 0.10
20	1.08 ± 0.05	0.20 ± 0.04	1.11 ± 0.10
21	1.16 ± 0.04	0.04 ± 0.03	0.58 ± 0.07
22	0.79 ± 0.02		
23	2.11 ± 0.13	1.20 ± 0.38	0.16 ± 0.03
24	1.01 ± 0.02	0.76 ± 0.09	0.100 ± 0.008
25	0.97 ± 0.03	0.90 ± 0.13	0.12 ± 0.01
Tap water			
26	1.14 ± 0.21	1.67 ± 0.23	0.18 ± 0.03
27	1.38 ± 0.07	0.22 ± 0.04	2.20 ± 0.22
28	2.08 ± 0.12	0.13 ± 0.05	5.61 ± 0.49
29	1.91 ± 0.08	0.27 ± 0.02	3.54 ± 0.28
30	1.54 ± 0.24		
31	3.35 ± 0.41		

ble 2. The $^{234}U/^{238}U$, $^{228}Ra/^{226}Ra$ and $^{226}Ra/^{238}U$ activity ratios, for the same samples, are given in Table 3. The measured activities covered wide ranges, from 0.59 mBq l^{-1} in *Oulmes* mineral water sample to about 308 mBq l^{-1} in the well water sample located at about 1 km from phosphates extraction site in *Khouribga* area for U, and from 0.46 mBq l^{-1} in *Kenitra* tap water sample to 3696 mBq l^{-1} in the *My Yacoub* mineral water sample for Ra. The $^{234}U/^{238}U$, $^{228}Ra/^{226}Ra$ and $^{226}Ra/^{238}U$ covered also wide ranges, they vary between 0.79 observed for well water not far from the phosphates extraction site, and 8.30 for *Thirhboula* cold spring water sample for $^{234}U/^{238}U$, between 0.05 in the *Oulmes* spring water and 1.67 in *Kenitra* tap water sample for $^{228}Ra/^{226}Ra$, and between 0.07 measured in *Settat* well water and 2115 in commercialized *Oulmes* mineral water for $^{226}Ra/^{238}U$. The errors quoted in Table 2 are one sigma uncertainties due to counting statistics.

4. Discussion

Among analyzed well water samples, samples No. 19 and 23 had the lowest activity of ^{238}U (4.46 mBq l^{-1} and 6.25 mBq l^{-1} respectively), samples No. 18 and 22 had the highest activities (about 165 mBq l^{-1} and 308 mBq l^{-1} respectively). In the 4 remaining samples, U activities ranged from 22.53 to 60.60 mBq l^{-1}. The mean activity of ^{238}U in analyzed well samples was about 30 mBq l^{-1}. The Ra activity measured for seven well water samples ranged from 1 to 25 mBq l^{-1} with a mean value of 9.8 mBq l^{-1}. The $^{226}Ra/^{238}U$ activity ratio varied between 0.07 and 1.14.

Except in samples No. 18 and 23 where $^{228}Ra/^{226}Ra$ is > 1, the activities of ^{228}Ra originating from ^{232}Th were lower than those of ^{226}Ra originating from ^{238}U. The $^{228}Ra/^{226}Ra$ ratio is more variable than $^{234}U/^{238}U$ because ^{228}Ra and ^{226}Ra origins are in different decay series, in which the parent ^{232}Th and ^{238}U have quite dissimilar chemical behaviours in solutions.

The radioactive disequilibrium between the two U isotopes, ^{238}U and its daughter ^{234}U in natural waters is well known [1, 3, 12, 15, 26, 27]. In the dissolved phase, the ^{234}U activity is generally in excess compared to that of ^{238}U resulting in an $^{234}U/^{238}U$ activity ratio > 1. The genesis of this excess is attributed to processes like preferential leaching of ^{234}U [13, 28], *in-situ* decay of alpha recoiled ^{234}Th [29] or leaching through alpha-recoil tracks [30, 31]. The $^{234}U/^{238}U$ activity ratio varied in well waters between 0.79 for the sample presenting the elevated ^{238}U activity and 2.11 measured in one of the samples presenting the lowest ^{238}U activity. Hussain and Krishnaswami [13] and Cowart and Osmond [32] have observed a reverse correlation between $^{234}U/^{238}U$ activity ratio and ^{238}U concentration in well waters from regions near Ahmedabad and in aquifers from Southern Texas. They have attributed this finding to changes in the oxidizing/reducing conditions of the aquifer environment, with high ^{238}U and low $^{234}U/^{238}U$ in the oxidizing zones and low ^{238}U and high $^{234}U/^{238}U$ in the reducing zones.

Except for the commercialized *Oulmes* water that is poor in U and rich in Ra, ^{238}U activity ranged from 3.01 to 17.88 mBq l^{-1} with a mean activity value of 7.72 mBq l^{-1} that is clearly lower than that of well water mean value (80 mBq l^{-1}). The Ra activity ranged from 9.1 to 3696 mBq l^{-1} with a mean value higher than 590 mBq l^{-1}. A comparison of the U and Ra activities in hot mineral water shows that large amounts of ^{226}Ra do not necessarily indicate a high concentration of U in the surrounding rocks. Often such an anomaly could be caused by Ra that has migrated from other areas and been deposited randomly in the fissures of the bedrock. U and Ra concentrations in groundwaters could also depend on the nature of surrounding rocks.

The $^{234}U/^{238}U$ activity ratios in spring waters were obviously higher than those in waters from wells. Considering the maximum statistical error, they varied from about 1 for commercialized *sidi Ali* water sample to a high value of 7.39 with a mean value of about 3.95 for hot springs, and from 2.53 to 8.30 with a mean value of about 4.85 for cold springs. The reverse trend in ^{238}U activity vs. $^{234}U/^{238}U$ activity ratio in hot spring waters suggests that the elevated temperatures and strong reducing conditions at depth in geothermal systems cause an acceleration of isotopic exchange processes. Reduction of U will hardly accelerate isotope exchange due to the lower solubility of U in oxides-

U(IV) form and expulsion of ^{234}U from crystalline system which will be preferentially leached from surrounding deposits as was mentioned above.

In geothermal sources where the temperature and the concentration of the chlorine are very elevated and the reducing potential is high, the $^{226}Ra/^{238}U$ activity ratios are often very large. Zukin *et al.* [33], and Herczeg *et al.* [34] have found, in samples of geothermal origin, the ratios in the order of 10^3 to 10^6. Indeed, in a reducing medium where U is much less mobile than Ra, the disappearance of sulphates allows more important concentrations of Ra in solution [35].

The measured ^{238}U and ^{226}Ra activities in cold springs were low and the measured values of $^{234}U/^{238}U$ were elevated. The activities and activity ratios varied between 2.19 and 3.21 mBq l^{-1} for ^{238}U, 2.45 and 10.5 mBq l^{-1} for ^{226}Ra, 0.75 and 3.30 mBq l^{-1} for ^{226}Ra, 2.53 and 8.30 for $^{234}U/^{238}U$, 0.27 and 0.31 for $^{226}Ra/^{226}Ra$, and between 0.86 and 4.79 for $^{226}Ra/^{238}U$.

In springs, both Ra and U distributions are affected by temperature, salinity, and redox condition. The decline of U concentration may result from the retrograde stability of uranyl carbonate complexes [36]. High temperature may increase Ra concentrations by reducing adsorption coefficients for the divalent Ra ions [37]. Solid solutions with celestite, barite, or other alkaline-earth sulphates or carbonates may control soluble Ra concentrations in some cases [38]. The removal of Ra from solution is principally by adsorption or cation exchange [39]. The aqueous chemistry of Ra may also be greatly influenced by redox state of the environment, but the effect is opposite to that for U. The measured $^{226}Ra/^{238}U$ ratios in our spring water samples varied from 0.86 to 4.79 for cold springs and from 1.79 to 2115 for hot springs.

Results obtained for tap water samples taken from 6 different Moroccan cities did not present any anomalous value of U and Ra activity, or in $^{234}U/^{238}U$, $^{226}Ra/^{226}Ra$ and $^{226}Ra/^{238}U$ ratios. Radioactivity in tap water depends on its source that could be rivers, dams, wells or springs. Activity in tap water varied between 2.5 and 15.70 mBq l^{-1} for ^{238}U, 0.46 and 45.80 mBq l^{-1} for ^{226}Ra with averages of 9.47 and 24.72 mBq l^{-1}, respectively. The activity ratios varied between 1.14 and 3.35 for $^{234}U/^{238}U$, 0.13 and 1.67 for $^{226}Ra/^{226}Ra$ and 0.18 and 5.61 for $^{226}Ra/^{238}U$.

The U activities can also be affected by salinity and seasonal variations. Indeed results reported in [7, 8] show seasonal variations in U activity of a factor of 2 to 3 without obviously changing $^{234}U/^{238}U$ ratio. The variation represents a random sampling of what is probably a fluctuation influenced by rainfall, run-off, and soil-leaching phenomena. The same results show a variation of U activity from 10 mBq l^{-1} for salinity of 0% to 46 mBq l^{-1} for salinity of 37.2%. Our samples have been sampled in the same season of spring.

5. Conclusion

Radiochemical analyses of 31 drinking water samples taken from wells, springs and tap water have allowed, for the first time in Morocco, to obtain data on the repartition of the principal natural radioelements in drinking waters from different sources. The obtained results (^{234}U, ^{238}U, ^{226}Ra and ^{226}Ra activities; $^{234}U/^{238}U$, $^{226}Ra/^{226}Ra$ and $^{226}Ra/^{238}U$ activity ratios) are similar to those given by data published for other regions of the world. This comparison shows that there is no significant radioactive pollution in analyzed drinking waters what contribute to reassure the Moroccan consumer.

The measured activities of ^{238}U and ^{226}Ra covered wide ranges, from 0.59 to about 308 mBq l^{-1} for the first, and from 0.46 to 3696 mBq l^{-1} for the second. The most elevated value of 3696 mBq l^{-1} was obtained for the *My Yacoub* spring water that is very loaded in dissolved salts and actually not used for drinking. The $^{234}U/^{238}U$, $^{226}Ra/^{226}Ra$ and $^{226}Ra/^{238}U$ covered also wide ranges, they varied from 0.79 to 8.30 for $^{234}U/^{238}U$, from about 0.04 to 1.67 for $^{226}Ra/^{226}Ra$, and from 0.07 to 2115 for $^{226}Ra/^{238}U$. A comparison of results repartition in investigated drinking waters show that: (1) the ^{238}U activities are higher in wells than in the others sources, (2) the hot mineral waters are generally characterized by low ^{238}U activities and high ^{226}Ra activities and $^{234}U/^{238}U$ activity ratios. This statement is due to the elevated temperatures and strong reducing conditions at depth in geothermal systems, (3) in cold spring waters, ^{238}U and ^{226}Ra activities vary in narrow ranges that suggests that there is no large variation in environmental conditions of investigated cold springs.

We can not generalize the obtained results for all drinking waters in Morocco because of the limited number of the analyzed samples. Although they gave a general idea of U and Ra radioisotopes activity repartition in wells, springs and tap water samples which could be used to orient the next samplings in order to establish a global distribution map of radioelements in drinking waters of Morocco. A comparison of anomalously high activities of uranium and radium radioisotopes with data obtained for no polluting regions of the world, could help us to detect the eventual radioactive pollution.

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