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ARTICLE

Study of the radiological impact caused by the extraction of the residue of a dicalcium phosphate industrial plant

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Abstract – In recent years, a decontamination project has been under way to remove the polluted sludge on the riverbed of the Ebro river, particularly in the area of Flix (Tarragona, Spain). This project started in 2011 and consists of the removal of the sludge and its treatment in a process that will eventually restore the river to its natural conditions. The sludge is a product of the historical dumping of contaminants by a chemical complex situated next to the river, and it contains a range of contaminants, such as heavy metals, semi- and volatile organic compounds, and radionuclides. Downstream of the complex, in the town of L'Ampolla, a drinking water treatment plant (DWTP) is located. This plant collects the water from the Ebro river and, after potabilisation, the plant supplies drinking water to the population of southern Catalonia. Due to the possible presence of radionuclides in the river water, it was considered important to monitor and control the radioactivity parameters regulated under current legislation for water consumption. For this reason, in this study, our aim is to evaluate if the decontamination work carried out in Flix has any effects on the radioactivity levels of both Ebro river and treated water, by means of the determination of gross alpha activity, gross beta activity and a group of gamma emitter radionuclides at three different sampling points in the period between 2008 and 2012. One sampling point was located a few kilometres from the Flix area and the other two were located before and after the DWTP, respectively. From the results obtained, it could be observed that no significant differences were obtained between the samples taken before and after the beginning of the decontamination process began, so it is important to highlight that this project has not affected the quality of the water supplied by the DWTP.

Keywords: drinking water treatment plant / radioactivity control / gross alpha / dicalcium phosphate industry

1 Introduction

Due to the lack of environmental legislation in Spain in the twentieth century, several chemical facilities were established along the banks of rivers, contaminating the waterways and accumulating residue on the riverbed through the course of their normal operation. This is the case of the dicalcium phosphate (DCP) industrial plant located in Flix (Tarragona, Spain). The DCP's production process using Moroccan phosphate rock started in 1973 and continued for about 25 years and, as a consequence of the activity of this facility, the Flix reservoir contains a large amount of contaminated sludge. Among the various contaminants, different studies in the literature have demonstrated the presence of several natural radionuclides such as ^{238}U, ^{226}Ra and ^{210}Pb in samples from the DCP factory and the sludge accumulated in the riverbed (Casacuberta *et al.*, 2009, 2011; Mola *et al.*, 2011). Mola *et al.* (2011) analysed different sludge samples taken in front of the DCP factory from different depths and they found a maximum concentration of 5,847 Bq.kg^{-1} and 2,499 Bq.kg^{-1} for ^{226}Ra and ^{210}Pb, respectively. Casacuberta *et al.* (2011) studied the specific concentration and fluxes of ^{238}U decay series at different stages of the DCP's production. They determined the radionuclide activity in the resulting products and by-products in the DCP industry.

After considering the potential hazard of having this toxic waste dumped by the DCP located in Flix reservoir, the authorities developed the project to decontaminate it with the aim of the removal of up to 1 million m^3 of contaminated river sediments, so the project can be considered a major decontamination project. The main objective of this project is to avoid the contaminated sludge, in a hypothetical situation in which the river flow can increase by, for example, the influence of weather conditions, spreading along the river's course and, consequently, contaminating different surrounding areas and affecting the population. In this area of the Ebro river, water is usually used for agricultural production, and the contaminants could be introduced into the food chain, and consequently may

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be incorporated into the human body. This project started in 2011 and its first step is to create a protected (still water) area, independent of flowing water from the Ebro, so that, throughout the period of the work to be undertaken inside the reservoir, the river can flow through a channel on the left bank of the reservoir. In the event that an incident occurs during the process, the working area remains confined and does not send pollution downstream[1]. After creating the protected area, the sludge is going to be removed, treated (10–20% of the material extracted) and stored in a dumping area. Moreover, the water generated during the treatment of the sludge will also be treated and returned to the river and, consequently, the Ebro river and its ecosystem will be restored. Moreover, it is important to remark that a few kilometres from the Flix area, there is a Nuclear Power Plant (NPP) that can also contribute to the radiological quality of the Ebro river water.

Downstream, in the town of Campredó, there is a drinking water treatment plant (DWTP) in L'Ampolla which collects water from the Ebro river to supply drinking water to the population of southern Catalonia. Under current legislation (Government of Spain, 2003), the radiological parameters in the outgoing water of the DWTP (which is destined for human consumption) have to be controlled. These parameters are gross alpha, residual gross beta and tritium activities, whose maximum allowed values are 0.1 $Bq.L^{-1}$, 1 $Bq.L^{-1}$ and 100 $Bq.L^{-1}$, respectively. Due to the presence of the NPP 100 km before the DWTP, the high activity concentrations of the residues of the Flix DCP factory and also the possible influence of the decontamination work on the quality of the river water, our proposal is, on one hand, to evaluate the radioactivity levels in the water collected from the Ebro River and the water supplied by the L'Ampolla DWTP, and on the other hand, to compare these results with others previously obtained by our research group (Palomo *et al.*, 2010) for different samples taken before the beginning of the decontamination project.

To perform our study, we selected three different sampling points: one located a few kilometres from the Flix area, after the NPP, and the other two located before and after the DWTP, respectively. For all the points, the gross alpha, gross beta, residual gross beta activities and a group of gamma emitter radionuclides were determined. Moreover, the activities of these gamma radionuclides in the sludge samples generated during the treatment of water were also determined.

2 Experimental part

2.1 Materials and reagents

All chemical reagents used in this study were of analytical grade. Nitric acid (65%) was supplied by J.T. Baker (Holland). KCl and NaCl standards of 100 $mg.L^{-1}$ were supplied by Merck (Darmstadt, Germany).

A solution of ^{241}Am with a nominal activity concentration of 4.68 ± 0.41 $KBq.g^{-1}$ and a solution of $^{90}Sr/^{90}Y$ with a nominal activity concentration of 4.75 ± 1.5 $KBq.L^{-1}$ were provided by Amersham International plc (Buckinghamshire, England).

A certified solution of ten gamma emitters (QCY-48) provided by CIEMAT (Madrid, Spain) covering an interval of energy between 60 and 1,836 KeV was used for gamma spectrometry calibration.

Samples were filtered with a 0.45-μm filter supplied by Whatman (Maidstone, UK).

2.2 Sampling points

To evaluate the potential radioactivity increase in Ebro river water produced as a consequence of the decontamination work carried out in Flix, in this study, radioactivity monitoring was performed in water samples collected and treated by the DWTP located in L'Ampolla (Tarragona, Spain), which belongs to the Consorci d'Aigues de Tarragona[2]. The treatment carried out in that plant consisted of different steps: coagulation, flocculation, decantation, sand filtration and granular carbon filtration. Three different sampling points were selected for this study, as shown in Figure 1. The first sampling point was Ebro river water collected in Ascó, a few kilometres downstream of the area of Flix, where the decontamination work is being performed, and after the NPP (point A in Figure 1). River water from the ingoing point of the DWTP located in Campredó was also analysed (point B in Figure 1), as well as the outgoing water from the DWTP (point C in Figure 1). From the different points samples were collected two times per week in the case of point A, once a month throughout the screening period for samples from sampling point B and twice a month in the case of samples from C.

Apart from the water samples, sludge samples produced during the water treatment were also analysed. One kilogram of the sludge with a high percentage of water (around 70%) was taken from the centrifuge every day and then the sludge sample was dried in a stove at a temperature of 110 °C. This procedure was repeated every day for a month and, at the end of the period, the dried sludge was homogenised and a fraction was crushed in a ball mill and sifted in a 250-μm sieve (Palomo *et al.*, 2010).

2.3 Determination of radioactivity parameters

As we have mentioned before, in this study the radioactive parameters determined in water samples were: gross alpha, gross beta, residual gross beta activities and gamma radionuclides. All the methods used for that purpose are described in previous studies of our group (Palomo *et al.*, 2007, 2010; Nieto *et al.*, 2013).

For the gross alpha and gross beta activity determination, the methods used consisted of the acidification of aliquots of 20 mL and 200 mL of water, respectively, by using HNO_3 at a pH of approximately 2. The samples were then evaporated at a controlled temperature (70 °C) to a few millilitres using a sand bath. Then, the samples were transferred to a weighed stainless steel planchet with an internal diameter of 5 cm (supplied by Tecnasa (Madrid, Spain) and then evaporated until dryness

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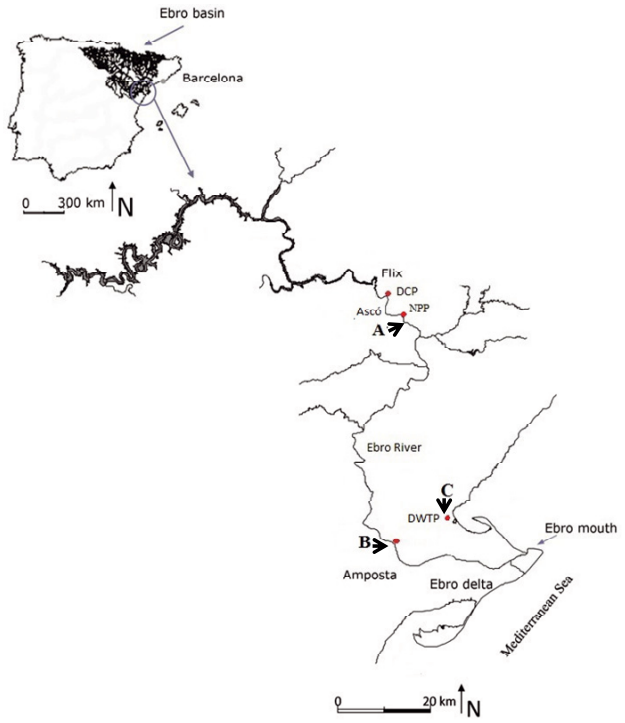

Figure 1. Location of the different sampling points and the dicalcium phosphate industry studied. DCP (dicalcium phosphate industry), A (sampling point in Ascó), NPP (nuclear power plant), B (ingoing water DWTP) and C (outgoing water DWTP).

under an infrared lamp. Afterwards, the samples were kept in a desiccator for a couple of days and then weighed and counted.

For the residual gross beta activity determination, the potassium concentration was measured with a flame photometer (Jenway, Model PFP7, UK).

Finally, a group of gamma-emitting radionuclides of natural and artificial origin were determined in different water and sludge samples. For water samples, the method consisted of the filtration of 500 mL of water, and then the samples were transferred to a 500-mL Marinelli beaker.

For solid samples, once the sample was crushed in a ball mill and sifted in a 250-μm sieve, 500 g of dried sludge was placed in a 500-mL Marinelli beaker.

2.4 Detectors

To measure the gross alpha activity, a zinc sulphide (ZnS (Ag)) scintillation counter (photomultiplier tube and base preamplifier, model 2000, Canberra, USA) with a voltage of 0.76 kV was used. A planchet containing ^{241}Am with an activity concentration of 100 Bq was used for the monthly calibration. The background of each detector was determined by counting an empty planchet for 5,000 minutes.

Gross beta activity was measured with a low background alpha/beta counter (LB770 Berthold Technologies, Germany) at a voltage of 1,650 V. The monthly calibration was performed using two planchets containing ^{241}Am with an activity of 100 Bq and ^{90}Sr/^{90}Y with an activity of 100 Bq, respectively. In this case, the background was determined by counting an empty planchet for 1,200 minutes.

The samples (for both gross alpha and gross beta activity) were measured using two cycles of 1,000 minutes and the activity was finally calculated by averaging the results.

Gamma emitters were measured with a high-resolution germanium detector (HPGe) model 202, Canberra Industries (Meriden, USA), equipped with a standard multichannel analyser. The operating conditions were a voltage of 4,500 V, a negative polarity and a relative efficiency of 20%. Genie 2000 software (Canberra Industries) was used to acquire and subsequently analyse the information provided by the gamma spectra. The samples were measured for 20 h and the activities of the samples were reported on the date of measurement.

All of the methods for water samples used in this study were validated and are included in the accreditation scope under the ISO/IEC 17025:2005 norm (International Standard, 2005).

3 Results and discussion

In this section, there is a summary of the most important results for each parameter studied at the different sampling points. The sampling point located in Ascó (point A, Figure 1) was selected because it is located downstream of the Flix DCP industrial plant. Moreover, analysing the ingoing and outgoing water samples (points B and C in Figure 1, respectively) enabled an evaluation of the efficiency of the DWTP treatment to eliminate these kinds of contaminants. In this section, an overview is given of the results obtained, with respect to each parameter.

3.1 Gross alpha activity

Due to the presence of alpha emitters with high activity in the waste generated by the DCP factory, the most important parameter to be evaluated in the river water was the gross alpha activity (Casacuberta *et al.*, 2011; Mola *et al.*, 2011). First of all, the gross alpha activity found at the sampling point in Ascó was evaluated, during the period between 2008 and 2012, in order to verify the possible occasional contamination of the river in this zone. In Figure 2, these results are shown, as well as the flow of the river in $dm^3.s^{-1}$. The first characteristic that can be observed in the figure is that the gross alpha activity measured in the samples is directly related to the river's flow because, when the flow of the river increases during certain months, the gross alpha activity decreases significantly. However, when the flow decreases, the gross alpha activity increases. During the period of time evaluated, the activity values obtained at point A of the sampling varied between 0.02 $Bq.L^{-1}$ and 0.15 $Bq.L^{-1}$. However, no increase in the gross alpha activity was observed in the river water due to the decontamination project carried out, since the decontamination work started in the last month of 2011. In this process, the contaminated sludge is removed, treated and eliminated. The water generated during the treatment of the sludge will be treated and returned to the river.

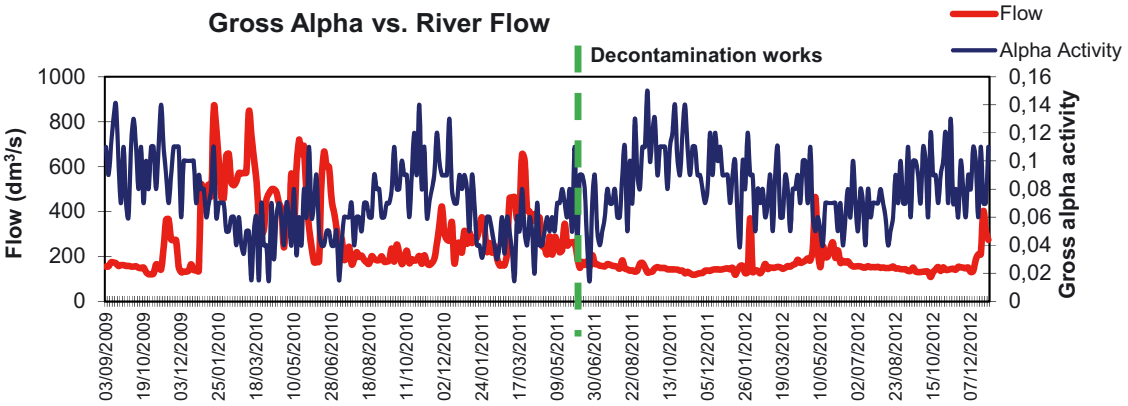

Figure 2. Gross alpha activity and riverflow obtained during the period 2008–2012 at the sampling point located in Ascó.

Table 1. Maximum, minimum and average activity (in $Bq.L^{-1}$) obtained each year for gross alpha activity measurements in the ingoing and outgoing water from the DWTP.

	Ingoing water			Outgoing water			
	Max	Min	Average	Max	Min	Average	Elimination
2008	0.14	<0.02	0.08	0.1	<0.02	0.05	38%
2009	0.18	0.05	0.10	0.14	<0.02	0.06	40%
2010	0.11	0.04	0.08	0.09	0.03	0.06	25%
2011	0.15	<0.02	0.09	0.1	<0.02	0.06	33%
2012	0.15	0.05	0.08	0.1	0.03	0.06	25%

Subsequently, an evaluation was made to identify whether the behaviour of this parameter was similar in the ingoing and outgoing water at the DWTP. In Table 1 the maximum, minimum and average gross alpha activities obtained in the ingoing and outgoing samples during the different years evaluated in this study are shown. As expected, similar behaviour was observed in both ingoing and outgoing water samples. It was observed that the gross alpha activity in the ingoing water samples had a value comprised between less than 0.025 and 0.18 $Bq.L^{-1}$. Therefore, it is important to highlight that the treatment carried out at the DWTP reduces this value to below 0.1 $Bq.L^{-1}$ in almost all the samples, which is the maximum value permitted under current legislation for waters devoted to human consumption (Government of Spain, 2003). When the gross alpha is higher than 0.1 $Bq.L^{-1}$, the total indicative dose has to be calculated and in the case that this value is lower than 0.1 $mSv.year^{-1}$, the water is also acceptable for human consumption. The results in the outgoing water samples analysed showed that only 2 out of 125 samples had a gross alpha value between 0.1 and 0.12 $Bq.L^{-1}$ (higher than the permitted legal value, which is 0.1 $Bq.L^{-1}$) (Government of Spain, 2003). For these samples, we performed an individual radionuclide identification in order to confirm that the water is suitable for human consumption. It could be confirmed that all of the alpha activity found in these samples was due to the presence of different natural radionuclides of uranium (^{234}U and ^{238}U) and radium (^{226}Ra) at concentrations in all cases below 50 $mBq.L^{-1}$. Due to the low concentration found for these radionuclides and using the data available in the Council Directive 2013/51/Euratom (Council Directive, 2013), it was confirmed that this water was suitable for human consumption since the total indicative dose was lower than 0.1 $mSv.year^{-1}$. We also evaluated, throughout the studied period of time, if there were any changes in the activity values obtained in the waters analysed. We could observe that the decrease in the gross alpha activity varied throughout the evaluated years between 25 and 40%, which was the maximum elimination level in 2009. Moreover, from the comparison with a previous study from our research group (Palomo *et al.*, 2010) in which the gross alpha activity was measured in the same samples during the period 2002 and 2007, we could confirm that the carbon filtration step included in the treatment in October 2008 increased the radiological quality of the treated water, since before this treatment was included the rate of elimination of gross alpha activity was around 15%. Moreover, no significant differences are observed between the gross alpha activities obtained because, in the study of Palomo *et al.* (2010), the average gross alpha activity in the outgoing DWTP water varied between 0.05 and 0.07 $Bq.L^{-1}$. The similar results obtained in this previous study and our study indicate that the decontamination work carried out in front of the DCP factory have not affected the gross alpha activity. Due to the relatively high activity values that in some cases are close to or even higher than the legal value, an exhaustive control of the outgoing water samples is important in order to fulfil the normative requirements (Montaña *et al.*, 2013). In this regard, it is important to remark that in the DWTP there are some efforts focused on the improvement of the water quality. The Consorci d'Aigües de Tarragona collaborated in a project which involves the inclusion of a tertiary treatment within the conventional treatment of the water, using a pilot plant based on reverse osmosis. The results of this treatment were satisfactory because the gross

Table 2. Average activity and standard deviation (in Bq.kg^{-1}) obtained each year for gamma emitters analysed in the sludge sample from the DWTP.

Radionuclide	2008	2009	2010	2011	2012
Natural origin					
^{228}Ac	176 ± 68	141 ± 20	183 ± 32	161 ± 48	69 ± 12
^{7}Be	129 ± 59	112 ± 70	167 ± 81	123 ± 70	147 ± 73
^{212}Bi	35 ± 4	23 ± 5	26 ± 3	22 ± 4	13 ± 4
^{214}Bi	541 ± 207	263 ± 78	323 ± 88	269 ± 88	65 ± 35
^{212}Pb	33 ± 9	37 ± 4	34 ± 8	32 ± 5	23 ± 7
^{214}Pb	543 ± 205	269 ± 75	326 ± 177	265 ± 86	83 ± 60
^{40}K	192 ± 76	272 ± 44	201 ± 77	150 ± 35	118 ± 49
^{208}Tl	9 ± 2	10 ± 1	21 ± 3	8 ± 2	5 ± 2
^{235}U	8 ± 3	9 ± 3	8 ± 2	10 ± 2	10 ± 2
Artificial origin					
^{137}Cs	1.5 ± 0.4	1.8 ± 0.3	1.8 ± 0.6	2.7 ± 0.8	0.9 ± 0.3
^{60}Co	13 ± 7	10 ± 5	5 ± 3	7 ± 1	9 ± 4
^{54}Mn	3 ± 1	2 ± 1	3 ± 1	3 ± 1	2 ± 1
^{110m}Ag	3 ± 2	5 ± 1	4 ± 2	5 ± 2	6 ± 4

alpha activity was reduced to levels below the minimum detectable activity, which was 0.025 Bq.L^{-1} (Nieto *et al.*, 2013).

After evaluating the values of gross alpha activity of the different samples analysed, it is considered that the radioactivity control performed along the river and on the ingoing water is sufficiently exhaustive.

3.2 Gross beta and residual gross beta activity

Because some of the radionuclides from the decay chains found in the sludge generated by the DCP factory may be beta emitters, as shown by Mola *et al.* (2011) in their study, the gross beta activity and the residual gross beta activity were also evaluated in the samples collected at all of the sampling points. The results for the gross beta activity do not show any differences among all of the samples analysed. In the samples collected in Ascó and the ingoing water of the DWTP, the values of gross beta activity were always lower than 0.3 Bq.L^{-1}. Meanwhile, the gross beta activity in the outgoing water of the DWTP was always lower than 0.2 Bq.L^{-1}. In all of the samples analysed, the principal contribution to the gross beta activity is the presence of ^{40}K, which is highly soluble in water. When the residual gross beta was evaluated in the samples analysed (river, ingoing, outgoing), it was near or lower than the minimum detectable activity (MDA), which in our case was 0.04 Bq.L^{-1}. The residual gross beta activity is the legally controlled parameter and its maximum activity level allowed in Spain under RD 140/2003 is 1 Bq.L^{-1} (Government of Spain, 2003). If the values obtained from all of the samples analysed are studied, it is observed that all of the samples were near the MDA. Therefore, a change in the control of beta activity may be proposed, as an exhaustive control of residual gross beta activity is not considered necessary, in light of the low variation in the results. As such, the plant can reduce the number of analyses. Moreover, with respect to the DCP factory in Flix, the residue discharge by the DCP factory probably has no effect on the gross beta activity measured at the DWTP.

3.3 Gamma radionuclides

In order to have more information about the individual isotopes that can be present in the analysed samples we evaluated the presence and activities of a group of gamma emitter radionuclides in the samples collected from the river and the outgoing water samples. For all these samples, the activity values obtained were always below the minimum detectable activity.

In the case of the sludge samples we could quantify several radionuclides derived from natural, industrial and fallout sources. Table 2 gives a summary of the average concentration activity values and their standard deviation of gamma emitters found in the sludge samples for each year under study. The reported values in the table correspond to the average of 12 different samples (one per month). As can be observed in the table, the gamma emitters that showed the highest concentration were the radionuclides present in the decay chain of ^{238}U, ^{232}Th and ^{40}K. This situation can be attributed to different factors, such as the geology of the areas where the Ebro river flows and the presence of the dicalcium phosphate industrial plant in Flix. Moreover, it can be observed that the results evaluated in the sludge samples confirm that, during the potabilisation treatment, the sludge generated concentrates some of the radionuclides present in the water treated. In a previous study by our group (Palomo *et al.*, 2010), in which sludge samples from the DWTP were studied, similar results were obtained. A significant decrease in the activity of three natural radionuclides (^{228}Ac, ^{214}Bi and ^{214}Pb) was only observed in 2012, in comparison with the other years. These three radionuclides are directly related to the presence of ^{228}Ra (^{228}Ac) and ^{226}Ra (^{214}Bi and ^{214}Pb) in the samples. Radium was determined in the contaminated sludge from Flix in the study of Mola *et al.* (2011), with activity concentrations of ^{226}Ra of up to 5,847 Bq.kg^{-1}. The decrease in the radium activity observed could be attributed to the isolation of the contaminated area in the river with a sheet pile wall at the end of the year 2011. So, in the future when the decontamination work is finished,

the activity concentration of some radionuclides is expected to be reduced in the river and, consequently, in the radioactivity content of the sludge generated by the water treatment plant.

In the same analysis of natural gamma emitters, some artificial radionuclides could also be detected, although these radionuclides are not related to the decontamination work carried out in Flix. In Table 2, the results obtained for these radionuclides were included to show the low activity concentration found for these radionuclides in comparison with the natural radionuclides detected in the sludge samples. For example, ^{137}Cs, ^{60}Co, ^{54}Mn and ^{110m}Ag were determined in the sludge samples. However, they were not present in all of the samples and the average value was near the MDA. The presence of these radionuclides can be attributed to the normal operation of the Nuclear Power Plant (NPP) or to fallout (^{137}Cs). The influence of the possible discharges of the NPP was also demonstrated through the determination of tritium in the samples obtained. For instance, although the tritium activity found in the outgoing water was always below the maximum value allowed under current legislation, in 30% of the samples analysed in the outgoing water, the tritium activity was higher than 10 Bq.L^{-1}.

4 Conclusions

One of the aims of this study was to evaluate the effect of the decontamination of the sludge from the DCP factory located upstream of the DWTP. In this respect, no significant differences could be observed between the results obtained in this and previous studies of the gross alpha and gross beta activity. Moreover, screening of the radioactivity parameters in the drinking water treatment plant in L'Ampolla (Spain) was performed, and the river water, and ingoing and outgoing water from the plant was analysed. It can be observed that all of the parameters studied show values below the maximum levels allowed under current Spanish legislation. It can also be observed that gross alpha activity is the most important parameter to control. Furthermore, the data related to the river flow is relevant because a correlation was observed between the flow of the river and the alpha activity present in the samples. The gross beta activity has not shown any variation since the decontamination work started, and the activities found were always near the minimum detectable activity. In the case of gamma analysis in the sludge samples, we observed a significant decrease in the activity concentration of three radionuclides, ^{228}Ac, ^{214}Bi and ^{214}Pb, that are directly related to the presence of ^{228}Ra (^{228}Ac) and ^{226}Ra (^{214}Bi and ^{214}Pb). This variation could be related to the isolation of the contaminated area in the river.

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References

Casacuberta N., Masqué P., García-Orellana J. (2009) Radioactivity contents in dicalcium phosphate and the potential radiological risk to human populations, *J. Haz. Mater.* **170**, 814-823.

Casacuberta N., Masqué P., Garcia-Orellana J. (2011) Fluxes of ^{238}U decay series radionuclides in a dicalcium phosphate industrial plant, *J. Haz. Mater.* **190**, 245-252.

Council Directive 2013/51/Euratom of (2013) Requirements for the protection of the health of the general public with regard to radioactive substances in water intended for human consumption, 22 October 2013.

Government of Spain (2003) Por el que se establecen los criterios sanitarios de la calidad del agua de consumo Humano [Establishment of Health Criteria for the quality of Water for Human Consumption]; Royal Decree 140/2003, Official State Bulletin BOE 45/2003. Gobierno de España, Ministerio de la Presidencia, Agencia Estatal: Madrid, Spain.

International Standard, ISO/IEC 17025:2005 (2005) General requirements for the competence of testing and calibration laboratories (Switzerland).

Mola M., Palomo M., Peñalver A., Aguilar C., Borrull F. (2011) Distribution of naturally occurring radioactive materials in sediments from the Ebro River reservoir in Flix (Southern Catalonia, Spain), *J. Haz. Mater.* **195**, 57-64.

Montaña M., Camacho A., Serrano I., Devesa R., Matia L., Vallés I. (2013) Removal of radionuclides in drinking water by membrane treatment using ultrafiltration, reverse osmosis and electrodialysis reversal, *J. Environ. Radioact.* **125**, 86-92.

Nieto A., Peñalver A., Aguilar C., Borrull F. (2013) Evaluation of the use of reverse osmosis to eliminate natural radionuclides from water samples, *Water Environ. Res.* **85**, 2265-2270.

Palomo M., Peñalver A., Borrull F., Aguilar C. (2007) Measurement of radioactivity in bottled drinkinf water in Spain, *Appl. Radiat. Isotopes* **65**, 1165-1172.

Palomo M., Peñalver A., Aguilar C., Borrull F. (2010) Radioactive evaluation of Ebro River water and sludge treated in a potable water treatment plant located in the south of Catalonia (Spain), *Appl. Radiat. Isotopes* **68**, 474-480.

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