Twelve-Year Monitoring Results of Radioactive Pollution in the Kazakh Part of the Syrdarya River Basin

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\begin{tabular}{ll}
\textbf{Received:} & 18 Apr 2018 \\
\textbf{Received in revised:} & 15 Aug 2018 \\
\textbf{Accepted:} & 15 Aug 2018 \\
\textbf{Published online:} & 8 Oct 2018 \\
\textbf{DOI:} & 10.32526/ennrj.17.1.2019.05 \\
\end{tabular}

\textbf{Keywords:}
Syrdarya/ Kazakhstan/ River pollution/ Radioactive pollution/ Uranium industry

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\begin{abstract}
Assessment of radioactive pollution of the Syrdarya river was carried out. A large number of water samples were collected over a twelve-year period from three zones: upstream of uranium mines; around uranium mines; and downstream of the mines. Samples were analyzed for gross $\alpha$-, $\beta$-activity and radionuclide concentrations. Gross $\alpha$-activity exceeded the permissible level in almost every water sample. Both gross $\alpha$- and $\beta$-activity in Baigekum village and PV-1 mine significantly exceeded safe levels throughout entire monitoring period. Concentrations of $^{230}$Th and $^{210}$Pb surpassed the national intervention levels in almost all water samples. In a number of samples from Baigekum village excessive concentration of $^{226}$Ra was observed. Furthermore, water samples collected from Tabakbulak in the spring of 2009 had extremely high levels of radionuclides. In general, elevated levels of radionuclides had been observed around the uranium mines and down the stream of Syrdarya since 2008-2009 when industrial-level production started at Zarechnoye, Khorasan and Irkol uranium deposits. The results suggest that radioactive pollution of Syrdarya in Kazakhstan is primarily caused by uranium mining activities. It is likely that the Syrdarya waters are not only unpalatable for human, but it may also not be suitable for household and agricultural use due to radioactive pollution.
\end{abstract}

1. INTRODUCTION

Syrdarya is the longest river in Central Asia and its basin spreads across Tajikistan, Kyrgyzstan, Uzbekistan and Kazakhstan. It flows to the northern remnants of the Aral Sea through South Kazakhstan and Kyzylorda regions of Kazakhstan and plays a crucial role for regional economies. Heavy metal contamination of Syrdarya is of greatest emerging concern as contaminations in surface and groundwater exceed World Health Organization (WHO) drinking water guidelines (Kawabata et al., 2008; Friedrich, 2009). It was also determined that the Syrdarya waters could not be used for agriculture and household purposes (Besterekov, 2013). Furthermore, it was identified that health hazards are significantly higher in downstream surface waters in Central Asia (Törnqvist et al., 2011; Bekturganov et al., 2016). Particularly, water contamination caused by uranium mining poses health risks to the population around Syrdarya. The issue of surface water contamination by radionuclides is particularly important given notable cancer incidences and high maternal and child morbidity and mortality in South Kazakhstan and Kyzylorda regions (Igissinov et al., 2011; Zetterström, 1998; Turdybekova et al., 2015).

Currently, Kazakhstan is the world’s top uranium producer, with almost 40\% of global production and as a result of a national program to become a world leader, production surged by more than 1000\% during 2001-2013 (Kazatomprom, 2018). The share of uranium in total export increased from 1.6\% in 2000 till 3.1\% in 2012 and it was the 5th largest export commodity (Akhmetov, 2017). Kazatomprom is a national operator of the uranium market in Kazakhstan and it has subsoil use rights on uranium deposits (IAEA, 2016). The race to become the world’s top uranium producer led to the environmental pollution (Arnoldy, 2013). Regional offices of the State Committee for Industrial and Mining Safety Supervision and the regional governments overlook adherence to the safety of the uranium mines (Conway, 2013; IAEA, 2016).

https://doi.org/10.32526/ennrj.17.1.2019.05
However, widespread corruption and rent-seeking undermine the integrity of environmental monitoring process (Conway, 2013).

Uranium mining in Kazakhstan is performed by in-situ leach (ISL), which is believed to be environmentally safe and cost effective method (Kazatomprom, 2018). However, it is known that ISL releases uranium, thorium, radium, radon and their respective progeny (Tweeton and Peterson, 1981; Kasper et al., 1979). The method also alters groundwater, causes spills of dangerous pollutants, contaminates aquifers and creates solid waste from excavations, injection and production wells (Fettus and McKinzie, 2012). Furthermore, surface pollution could be minimal, but underground impacts are significant (Mudd, 1998). ISL is employed in locations with different hydrochemical properties of groundwater. It has different effects on uranium compounds and they are not always advantageous for technological process.

Shu-Syrdarya uranium region, consisting of 15 deposits of commercial interest, has been the most important in Kazakhstan due to significant reserves (Fyodorov, 2000). Total reserves of Syrdarya uranium province consist of around 250 tons of uranium with the depth of uranium ore between 100-800 meters (World Nuclear Association, 2018; Fyodorov, 1997). The deposits are hosted by sandstones and characterized by high concentrations of rare and dispersed elements (Jaireth et al., 2008). It is possible that the ISL process could cause migration of radionuclides to the stem of Syrdarya (Kadyrzhanov et al., 2005).

It was identified that radioactivity levels in ground and wastewaters at the production sites exceed the national standards (Kayukov, 2008). Furthermore, it is likely that the uranium mining may have negative health effects on the nearby population (Bersimbaev and Bulgakova, 2015). Arnoldy (2013) and Conway (2013) suggested that Kazatomprom neglects environmental concerns related to ISL mining and considers investments in safety of operations as unnecessary capital costs and the operator also claims that nature will self-restore itself at the mining sites. Moreover, due to significant costs and low population density around mines, the need for treatment of contaminated waters has been considered unnecessary in the past (Fyodorov, 2000). Nevertheless, population density around Syrdarya is notable (CIESIN, 2016). On top of that, the river is the major source of irrigation in South Kazakhstan and Kyzylorda regions.

The regional economy of South Kazakhstan is primarily based on agriculture. Regional agricultural output contributes to 12% of the national agricultural production (Akhmetov, 2017). Almost 90% of rice in Kazakhstan is grown in Kyzylorda region. Hence, the quality of produced rice depends on pollution level of Syrdarya as the main source of water for rice farming. Moreover, acute and long-term health effects may occur due to water use for household purpose, drinking, boating, swimming, consumption of contaminated fish, etc.

The presence of radionuclides in Central Asian Rivers drew attention of scientists due to the history of radioecological problems in the former USSR. The three-year Navruz project was designed to bring together Kazakh, Uzbek, Tajik and Kyrgyz scientists to perform radioecological monitoring of Syrdarya and Amudarya rivers (Yuldashev et al., 2002; Yuldashev et al., 2005). The analysis of transboundary radionuclide contamination of Syrdarya was based on water samples from 60 monitoring sites (15 in each country) and analyzed for radiation readings, 71 radionuclides and heavy metals (Barber et al., 2005). The project concluded that radionuclide contamination of Syrdarya in Kazakhstan was caused by inflows from Uzbekistan, Keles and Arys river tributaries. Furthermore, the highest radionuclide concentrations were observed near Shieli uranium deposit in Kyzylorda region (Kadyrzhanov et al., 2005; Solodukhin et al., 2004).

Kawabata et al. (2008) investigated surface and drinking water at 21 sites in the Aral-Syrdarya area for uranium concentration during August, 2003. The results indicated that uranium concentration in drinking water samples from two sites with shallow wells exceeded WHO guidelines significantly (WHO, 2011), while the samples from deeper wells showed lower concentration of uranium. It was suggested that phosphate fertilizers and uranium mining were the sources of contamination.

Satybaldiyev et al. (2015) analyzed concentrations of $^{238}\text{U}$, $^{234}\text{U}$ and $^{226}\text{Ra}$ radionuclides from 12 surface water samples collected along Syrdarya between the cities of Turkestan and Kyzylorda in May, 2013. Although all but one sample indicated uranium concentrations exceeding the WHO guideline level, it was concluded that they were within the level accepted for drinking water. It
was also suggested that the uranium mining does not affect the quality of Syrdarya waters.

Unfortunately, after management change at the national operator, independent research organizations were barred from collecting water and soil samples for investigation around active mines. Hence, no radioecological assessment studies after 2015 were carried out.

2. METHODOLOGY

Unlike previous studies, this analysis is based on longer period of sampling (2000–2012). Unfortunately, due to limited research budget, continual sampling could not be achieved and no samples were collected in 2010. The period after 2008–2009 is of particular interest due to commencement of production at Zarechnoye, Khorasan and Irkol uranium deposits. The objectives of this analysis are to assess the radioecological situation of Syrdarya, understand the migration and areas of accumulation of radionuclides. The samples are also analyzed for concentrations of 11 radionuclides. The research compares concentration of radionuclides and α- and β-radioactivity in samples with national norms of radiation safety. Given the national plans of uranium mining expansion, it is particularly important to understand the possible contribution of the existing uranium mines on radioactive pollution of Syrdarya.

2.1 Study area

Zoning method in river water sampling is used to identify radionuclide contamination hazard prone areas (Salishev, 1987; Buksa and Myach, 1990). Following the stream of Syrdarya and location of uranium mines, three zones are defined:

1) Upstream of uranium producing mines (Chinaz and Shardara);

2) Near the mines (Tabakbulak, Shaulder, Tomenaryk, Rudoupravlennie-6 (RU-6) and Baigekum);

3) Settlements located after the mines, downstream of Syrdarya (Kyzylorda, Amangeldy and Amanotkel).

A total of 43 surface water samples were collected from Syrdarya at the following 13 sites from south to north-west: Chinaz, Shardara, Tabakbulak, Shaulder, Tomenaryk, Shiel, RU-6, PV-1, PV-2, Baigekum, Kyzylorda, Amangeldy, Amanotkel as seen in Figure 1.
Chinaz is a town in Tashkent region of Uzbekistan, located on the confluence of Chirchiq and Syrdarya rivers. The reason for selecting this site is to analyze the Syrdarya water quality before the Shardara dam, while the samples from Shardara town in South Kazakhstan region aim to analyze water discharged from the reservoir. Shardara dam was constructed in the 1960s with the primary purpose of irrigation and hydropower production.

There are six main uranium producing deposits in the area. One is located in South Kazakhstan region, while others are in Kyzylorda region (World Nuclear Association, 2018). Zarechnoye uranium deposit is located in Otrar district of South Kazakhstan near Tabakbulak village, west of Syrdarya. Shaulder village is located 50 km east from the deposit on the banks of Syrdarya. Zarechnoye was prepared for industrial production in 1991. However, following the collapse of the USSR it was conserved. Preparation works to restart production started in 2006 and production reached 500 tons of uranium in 2009.

Northern and Southern Khorasan uranium deposits are located in Zhanakorgan district of Kyzylorda region, on the left bank of Syrdarya. Northern Khorasan is the largest uranium deposit in Kazakhstan, where test mining began in 2008 and commercial in 2013 Tomenaryk village is located north-east from this deposit on the banks of Syrdarya.

Irkol and Karamuryn uranium deposits are located in Shiehi district of Kyzylorda region. RU-6, located in Shiehi village, administers uranium production from Northern and Southern Karamuryn deposits. RU-6 is expected to sustain production of yellow cake at 1,000 tons/year for another 25 years. It is the oldest mine group of the uranium province, where production started in the 1980s, while mining at Irkol commenced in 2008. Baigekum village is located north-west from Shiehi.

Kyzylorda city, Amanotkel and Amaneledy villages are located downstream of Syrdarya. Kyzylorda is a capital of Kyzylorda region with population of almost 200,000. Amanotkel and Amaneledy are the villages in Syrdarya district and Aral district respectively. Analysis in this area could help to understand the level of pollution downstream from uranium mines.

### 2.2 Sampling and analysis

Surface water samples were collected in accordance with the existing river water sampling method in Kazakhstan (VSEGINGEO, 1990). Samples were taken from the surface water layer (0.5-1 meter) of the river. The total volume of one sample comprised 20 liters. The samples were packed in polyethylene bottles and transported for analysis within 1-2 days to the certified laboratory at the Central Experience Methodical Expedition (CEME, 2018), where Total Dissolved Solids (TDS) in milligrams/liter (mg/L), gross α-, β-radioactivity and radionuclide concentrations were measured by UMF-2000 radiometer.

Then, the samples were evaporated to dryness and muffed for 1 hour at 350 °C. Ethyl alcohol was added into porcelain dish as a solvent, residuals were removed from the walls of the cup and the solution was poured into a cuvette. The mixture was then dried under a lamp until homogeneous layer. An Ortec DSPEC LF spectrometer was used in accordance with the technique of measuring at the γ-spectrometer MI 2143-91 to determine radionuclide concentrations in the sample (VNNIIFTRI, 1991). Analyzed radionuclides are $^{226}$Ra, $^{232}$Th, $^{235}$U, $^{227}$Th, $^{223}$Ra, $^{228}$Th, $^{228}$Ra, $^{40}$K (Potassium-40), $^{210}$Pb, $^{230}$Th and $^{137}$Cs. Gross α- and β-activity and radionuclide concentrations are compared with radiation safety norms in Kazakhstan presented in Table 1.

| Radionuclide | Activity (Bq/L) |
|--------------|-----------------|
| $^{226}$Ra (Radium-226) | 0.49 |
| $^{232}$Th (Thorium-234) | 40 |
| $^{235}$U (Uranium-235) | 2.9 |
| $^{227}$Th (Thorium-227) | 16 |
| $^{223}$Ra (Radium-223) | 1.4 |
| $^{228}$Th (Thorium-228) | 1.9 |
| $^{228}$Ra (Radium-228) | 0.2 |
| $^{210}$Pb (Lead-210) | 0.11 |
| $^{230}$Th (Thorium-230) | 0.65 |
| $^{137}$Cs (Caesium-137) | 11 |
| Gross α-activity | 0.2 |
| Gross β-activity | 1.0 |

Table 1. Kazakh national intervention levels of radionuclides and permissible levels of gross α- and β-activity in water samples (Ministry of National Economy of Kazakhstan, 2015)
3. RESULTS AND DISCUSSION

Results of this analysis indicate that TDS, gross α- and β-activity values are significantly high almost at every site as seen in Table 2. TDS tends to increase during ISL. Data indicates that average TDS is higher in spring and fall than in winter. It is lower upstream of the Shardara dam, increases when water is discharged from the reservoir, significantly higher around the mines and declines downstream. Extremely high values were observed at PV-1 and Tabakbulak in W2007 and S2009.

Overall gross α-radioactivity has declined over the years, but remained higher than the permissible level. Gross α-activity exceeds the permissible level in almost every sample, while gross β-activity exceeds in Baigekum (S2001, F2001, S2002), Kyzylorda (W2003), PV-1 (W2007) and Tabakbulak (S2009). Gross α- and β-activity is significantly high in the Baigekum and PV-1 mines throughout the entire observation period. The sample from Tabakbulak in S2009 exceeds safety norms for gross α- and β-radioactivity do not follow seasonal variations. They have declined in Shardara, Tomenaryk, Shiel, RU-6, Baigekum and Kyzylorda, while the values have increased in Tabakbulak and PV-1 during the observation period. Moreover, in Shaulder gross α-activity has declined, while gross β-activity has increased.

Table 2. Gross α- and β-activity measurements (W-winter, S-spring and F-fall; samples exceeding intervention level are highlighted)

| Season/year | Sample point | TDS (mg/L) | Gross α-activity (Bq/L) | Gross β-activity (Bq/L) |
|-------------|--------------|------------|-------------------------|-------------------------|
| W2000       | Shardara     | 1422       | 1.18±0.37               | 0.76±0.17               |
| S2001       | Chinaz       | 870        | 0.21±0.13               | 0.24±0.11               |
|             | Shardara     | 850        | 1.33±0.29               | 0.51±0.19               |
|             | Baigekum     | 1200       | 24.77                   | 3.96                    |
| F2001       | Baigekum     | 1600       | 20.59                   | 3.51                    |
| W2002       | PV-1         | 950        | 0.38                    | 0.33                    |
|             | RU-6         | 1740       | 0.76                    | 0.68                    |
| S2002       | Baigekum     | 2090       | 29.52                   | 8.68                    |
|             | Tomenaryk    | 420        | 1.58                    | 0.52                    |
|             | Kyzylorda    | 700        | 2.30                    | 0.59                    |
| W2003       | Kyzylorda    | 960        | 3.12                    | 1.52                    |
|             | PV-1         | 950        | 0.38                    | 0.33                    |
|             | RU-6         | 1740       | 0.76                    | 0.68                    |
| S2003       | Amanotkel    | 840        | 0.61                    | 0.33                    |
|             | Kyzylorda    | 950        | 0.46                    | 0.33                    |
| W2004       | PV-1         | 1950       | 0.39                    | 0.45                    |
|             | RU-6         | 950        | 0.20                    | 0.54                    |
| S2005       | Kyzylorda    | 940        | 0.17                    | 0.38                    |
|             | PV-1         | 1810       | 0.24                    | 0.26                    |
|             | PV-2         | 1770       | 0.31                    | 0.26                    |
| W2006       | Baigekum     | 590        | 0.08                    | 0.25                    |
| S2006       | Kyzylorda    | 910        | 0.29                    | 0.57                    |
|             | Tomenaryk    | 860        | 0.244                   | 0.39                    |
| F2006       | Baigekum     | 1450       | 0.50                    | 0.57                    |
| W2007       | RU-6         | 880        | 0.24                    | 0.35                    |
|             | PV-1         | 5330       | 1.39                    | 2.11                    |
|             | Tomenaryk    | 950        | 0.22                    | 0.43                    |
### Table 2. Gross α- and β-activity measurements (W—winter, S—spring and F—fall; samples exceeding intervention level are highlighted) (cont.)

| Season/year | Sample point | TDS (mg/L) | Gross α-activity (Bq/L) | Gross β-activity (Bq/L) |
|-------------|--------------|------------|------------------------|------------------------|
| F2008       | Baigekum     | 1910       | 0.222                  | 0.104                  |
|             | Shieli       | 1870       | 0.319                  | 0.12                   |
|             | Tabakbulak   | 2300       | 0.299                  | 0.154                  |
|             | Shoulder     | 2100       | 0.408                  | 0.123                  |
| W2009       | Baigekum     | 1620       | 0.63                   | 0.249                  |
|             | Shieli       | 1150       | 0.724                  | 0.259                  |
|             | Tabakbulak   | 2050       | 0.41                   | 0.257                  |
|             | Shoulder     | 2350       | 0.26                   | 0.175                  |
| S2009       | Tabakbulak   | 5230       | 158                    | 408.1                  |
|             | Baigekum     | 1680       | 1.69                   | 0.706                  |
|             | Shieli       | 2200       | 0.56                   | 0.169                  |
|             | Tomenaryk    | 1950       | 0.581                  | 0.187                  |
| W2011       | Shardara     | 1340       | 0.55                   | 0.421                  |
|             | Amangeldy    | 1069       | 0.54                   | 0.482                  |
| W2012       | Baigekum     | 860        | 0.47                   | 0.182                  |
|             | Shieli       | 1430       | 0.20                   | 0.074                  |

Radionuclide concentrations in samples are presented in Table 3. It is likely that the main contribution to radioactivity comes from the decay products of $^{238}$U, $^{235}$U and $^{232}$Th. $^{226}$Ra, $^{228}$Ra $^{210}$Pb and $^{234}$Th are the decay products of the radionuclides. Decay chains of parent isotopes also contain radon gas and another contributing radionuclide is $^{40}$K. Furthermore, $^{226}$Ra, $^{234}$Th and $^{40}$K tend to migrate faster than others.

The results indicate that concentrations of $^{230}$Th and $^{210}$Pb significantly exceed the national intervention levels in almost all samples. Although $^{235}$U concentration from Tabakbulak (S2009) was close to intervention level, concentrations of $^{235}$U, $^{228}$Th and $^{137}$Cs have never exceeded safe levels. The concentration of $^{226}$Ra significantly exceeded intervention levels in Baigekum (S2001, S2002, S2009) and Tabakbulak (S2009) by 4.7, 9.1, 1.3 and 108.6 times respectively. The latter sample also had excessive concentrations of $^{234}$Th, $^{227}$Th, $^{223}$Ra, $^{228}$Ra, $^{210}$Pb and $^{230}$Th. Samples from Shardara (W2011), Amangeldy (W2011), Baigekum (W2012) and Shieli (W2011) had excessive concentrations of $^{228}$Ra.

In general, water inflows with elevated levels of radioactivity and radionuclide concentrations from Uzbekistan enters Shardara dam, where polluted water is accumulated and later discharged. Discharge of uranium mining effluents occurs further downstream around the mines. Polluted waters are observed downstream from the mines and eventually inflow into the Aral Sea. It should be noted that lack of continuous sampling is a major limitation of this study.

Radioecological monitoring of Syrdarya around uranium mines is currently performed by subsidiaries of the national operator, which undermines the integrity of the process. In the future, outside research organizations should be allowed to collect and analyze water and soil samples to verify independently the results of internal monitoring. Moreover, further research is needed to assess health impacts related to radiological pollution of Syrdarya.
| Location | 226Ra (Bq/L) | 234Th | 238U | 227Th | 228Ra | 228Th | 40K | 210Pb | 230Th | 137Cs |
|----------|--------------|-------|-------|-------|-------|-------|-----|-------|-------|-------|
| W2000    |              |       |       |       |       |       |     |       |       |       |
| Shardara | 0.071        | 0.12  | 0.01  | -     | -     | <0.008| 0.18| 0.17   |       | <0.006|
| Chinaz   | <0.015       | <0.08 | <0.008| -     | -     | <0.01 | <0.03| 0.19   | -     | <0.08  |
| S2001    |              |       |       |       |       |       |     |       |       |       |
| Shardara | 0.13         | <0.06 | <0.013| -     | -     | <0.016| <0.05| 0.18   | -     | <0.014 |
| Baigekum | 2.29         | 1.49  | 0.014 | -     | -     | <0.028| <0.06| 0.18   | -     | 0.016  |
| F2001    |              |       |       |       |       |       |     |       |       |       |
| Baigekum | 0.021        | -     | -     | <0.036| 0.02  | 0.009 | 0.02| 0.26   | -     | <0.007 |
| W2002    |              |       |       |       |       |       |     |       |       |       |
| PV-1     | 0.047        | -     | -     | -     | -     | <0.011| 0.031| 0.21   | -     | <0.009 |
| Ru-6     | 0.062        | -     | -     | -     | -     | <0.033| 0.041| <0.18  | -     | <0.02  |
| S2002    |              |       |       |       |       |       |     |       |       |       |
| Baigekum | 4.47         | 0.94  | 0.08  | 0.09  | 0.24  | 0.06  | 0.012| 0.4    | 1.17  | <4.11  |
| Toemenaryk | 0.21     | <0.05 | <0.07 | <0.06 | <0.05 | <0.018| <0.06| <0.23  | <0.09 | <1.39  |
| Kyzylorda | 0.19        | 0.168 | 0.016 | <0.08 | <0.07 | 0.023 | <0.08| <0.20  | <0.19 | <2.3   |
| W2003    |              |       |       |       |       |       |     |       |       |       |
| Kyzylorda | 0.45        | -     | -     | 0.074 | 0.067 | <0.032| <0.08| <0.27  | -     | <0.028 |
| PV-1     | 0.047        | -     | -     | <0.001| <0.001| <0.011| 0.031| 0.21   | -     | <0.009 |
| Ru-6     | 0.062        | -     | -     | <0.002| <0.002| <0.033| <0.041| <0.18  | -     | <0.015 |
| S2003    |              |       |       |       |       |       |     |       |       |       |
| Amanotkel | <0.008      | 0.113 | -     | <0.032| <0.032| <0.01 | 0.028| 0.14   | <0.078| <0.83  |
| Kyzylorda | 0.021       | 0.12  | -     | <0.025| <0.025| <0.008| <0.022| 0.17   | <0.062| <0.69  |
| W2004    |              |       |       |       |       |       |     |       |       |       |
| PV-1     | 0.028        | 0.13  | -     | <0.047| <0.035| <0.013| 0.047| 0.14   | <0.72  | <1.8   |
| Ru-6     | 0.164        | <0.09 | -     | <0.053| <0.04  | <0.009| 0.041| 0.21   | <0.81  | <2.2   |
| S2005    |              |       |       |       |       |       |     |       |       |       |
| Kyzylorda | <0.015      | 0.14  | 0.0083| -     | -     | <0.0101| <0.036| 0.21   | <0.058| <0.69  |
| PV-1     | <0.014       | <0.058| <0.0066| -     | -     | <0.0071| <0.032| <0.13  | <0.06  | <0.73  |
| PV-2     | <0.014       | 0.065 | 0.0063| -     | -     | <0.0095| <0.024| <0.15  | <0.061| <0.75  |
| W2006    |              |       |       |       |       |       |     |       |       |       |
| Baigekum | 0.011        | 0.057 | <0.0085| -     | -     | 0.013  | <0.034| <0.13  | <0.05  | <0.58  |
| S2006    |              |       |       |       |       |       |     |       |       |       |
| Kyzylorda | 0.019       | 0.109 | <0.009| -     | -     | 0.043  | <0.049| 0.2    | <0.055| <0.87  |
| Toemenaryk | 0.024   | 0.072 | 0.0076| -     | -     | 0.01   | <0.049| <0.21  | <0.062| <0.78  |
| F2006    |              |       |       |       |       |       |     |       |       |       |
| Baigekum | <0.034       | <0.14 | <0.0121| -     | -     | <0.0265| <0.085| <0.37  | <0.161| <1.7   |
| W2007    |              |       |       |       |       |       |     |       |       |       |
| Ru-6     | 0.017        | 0.122 | 0.0079| -     | -     | <0.0061| <0.024| <0.1   | <0.038| <0.43  |
| PV-1     | 0.062        | 0.191 | <0.021| -     | -     | 0.0279 | <0.132| 1.22   | <0.228| <2.55  |
| Toemenaryk | 0.013  | 0.158 | 0.0013| -     | -     | 0.009  | <0.021| <0.09  | <0.035| <0.39  |
| F2008    |              |       |       |       |       |       |     |       |       |       |
| Baigekum | <0.06        | 0.17  | <0.017| -     | -     | <0.03  | <0.12  | <6.0   | <0.27  | <2.2   |
| Shieh    | <0.05        | 0.16  | 0.016 | -     | -     | <0.029 | <0.11  | <6.0   | <0.26  | <2.1   |
| Tabakbulak | 0.078     | 0.12  | <0.015| -     | -     | <0.035 | <0.13  | <6.0   | <0.23  | <2.3   |
| Shaulder | 0.036        | 0.23  | 0.017 | -     | -     | <0.023| <0.12  | <5.0   | <0.23  | <2.3   |

Table 3. Radionuclide concentrations analysis (samples exceeding intervention level are highlighted)
Table 3. Radionuclide concentrations analysis (samples exceeding intervention level are highlighted) (cont.)

| Radionuclide concentrations, Bq/L | 226Ra | 234Th | 235U | 227Th | 223Ra | 238Th | 228Ra | 40K | 210Pb | 230Th | 137Cs |
|-----------------------------------|-------|-------|------|-------|-------|-------|-------|-----|-------|-------|-------|
| W2009                             |       |       |      |       |       |       |       |     |       |       |       |
| Baigekum                          | 0.039 | 0.25  | 0.0184 | -    | -    | 0.033 | <0.06 | <6.0 | <0.14 | <1.2  | <0.45 |
| Shieli                            | 0.05  | 0.23  | 0.019 | -    | -    | 0.021 | <0.11 | <6.0 | <0.25 | <2.1  | <0.45 |
| Tabakbulak                        | 0.046 | 0.18  | <0.019 | -    | -    | <0.024 | <0.11 | <6.0 | <0.27 | <2.3  | <0.4  |
| Shoulder                          | 0.054 | <0.12 | <0.018 | -    | -    | <0.035 | <0.11 | <6.0 | <0.18 | <2.0  | <0.45 |
| S2009                             |       |       |      |       |       |       |       |     |       |       |       |
| Tabakbulak                        | 53.2  | 67.9  | 1.19 | 30.6  | 25.3  | 0.93  | <2.6  | <7.0 | 124.0 | 372   | <0.6  |
| Baigekum                          | 0.638 | 0.27  | <0.026 | <0.12 | <0.11 | 0.033 | <0.12 | <6.0 | <0.29 | <2.5  | <0.4  |
| Shieli                            | 0.045 | 0.26  | 0.015 | <0.11 | <0.1  | 0.033 | <0.11 | <6.0 | <0.23 | <2.2  | <0.4  |
| Tomenaryk                         | <0.05 | 0.17  | 0.015 | <0.11 | <0.1  | 0.031 | <0.11 | <6.0 | <0.26 | <2.1  | <0.4  |
| W2011                             |       |       |      |       |       |       |       |     |       |       |       |
| Shardara                          | 0.12  | 0.26  | <0.04 | <0.07 | <0.022 | -    | <0.25 | <6.0 | <0.5  | <4.0  | <0.4  |
| Amangeldy                         | <0.10 | 0.25  | <0.04 | <0.06 | <0.024 | -    | <0.24 | <6.0 | <0.5  | <4.5  | <0.4  |
| W2012                             |       |       |      |       |       |       |       |     |       |       |       |
| Baigekum                          | <0.06 | 0.23  | <0.023 | <0.16 | <0.16 | <0.045 | <0.25 | <3.0 | <0.4  | <3.5  | <0.19 |
| Shieli                            | 0.07  | 0.25  | <0.024 | <0.06 | <0.16 | <0.06 | <0.24 | <4.0 | <0.4  | <3.5  | <0.3  |

4. CONCLUSIONS

The uranium industry has become an important source of income for the resource-oriented Kazakh economy. Expansion of production likely leads to radioactive pollution of Syrdarya. The results of this study indicate that both inflow and outflow water samples from Shardara dam contain elevated levels of radioactivity. However, it is likely that most radioactive water pollution of the Kazakh part of the Syrdarya river basin occurs around active uranium mines.

This twelve-year monitoring of Syrdarya indicates that gross activity exceeds permissible level in almost every water sample throughout the entire observation period. Gross β activity is higher around the Karamuryn uranium deposit, while commencement of production at Zarechnoye likely caused extremely high gross α, β activity and radionuclide concentrations in water samples from sites around mines and downstream of Tabakbulak in 2009. In general, it is most likely that elevated levels of radionuclide concentrations in samples from sites around mines and downstream of Tabakbulak in 2009 and onwards are caused by expansion of uranium production.

Based on WHO drinking water guidelines (WHO, 2011), it could be said that water from Syrdarya is unacceptable due to excessive TDS and dangerous radionuclide concentrations. Likewise, it is possible that the river water is not suitable for household and agricultural use. There is growing evidence that urine production in the region causes radioactive pollution of Syrdarya. Hence, there is an urgent need to thoroughly assess the safety and environmental effects of ISL technology in Kazakhstan.

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