International Journal of Smart Grid and Clean Energy

# Environment pollution of uranium in-situ leaching and its protection measures

Kang Jian Qiao, Li Zhao Kun, Deng Hui Dong, Deng Jin Xun, Ma Jia

*Beijing Research Institute of Chemical Engineering and Metallurgy, No.145 Jiukeshu, Tongzhou District, Beijing, 101149, China*

**Abstract**

With the development of nuclear power station, the requirement for uranium resources assumes an uptrend. In situ leaching technology is a kind of advanced uranium mining technology. Compared with traditional uranium mining methods, the in-situ leaching uranium method is less harmful to environment, but the effect of in-situ leaching on the atmosphere, soil, surface water, especially groundwater cannot be ignored. In this paper, on the basis of analyzing the pollution sources, measures to protect the environment are brought forward, which can help us to minimize the pollution of the in-situ leaching technology.

*Keywords: in-situ leaching of uranium; environment pollution; environment protection*

## 1. Introduction

The development of nuclear power has brought opportunities to the natural uranium industry. Strengthening the development capability of uranium resources is in line with the current needs of nuclear power development. With the development and utilization of uranium resources, the pollution of radioactive materials to the environment will inevitably occur in the process of uranium mining.

With the progress of society and the improvement of environmental awareness, people pay more and more attention to the environmental protection of radioactive pollution. Although the so-called "green technology" of in-situ leaching of uranium is widely adopted for its low environmental pollution, the pollution caused to the environment to some extent cannot be ignored.

## 2. Pollution Sources and Hazards of In-Situ Leaching Technology

Due to the particularity of technology of in-situ leaching, although this technology has no damage to the environment, because there is no tailings and waste rock, but as a result of leaching agent injection, ore-bearing aquifer geochemical environment changes, the injection of the leaching agent not only react with uranium ore, but also react with rock forming minerals, resulting in the change of groundwater quality [1].

The degree of groundwater pollution caused by leaching mining is different in different countries and mineral deposits. Table 1 shows the changes of main substances in groundwater quality before and after Honeymoon acid leaching in the United States. As can be seen from Table 1, the content of some substances in water increased by dozens or even hundreds of times. The Straz deposit in the Czech republic has injected more than 4 million tons of sulfuric acid and other reagents into the ground since it was mined in 1968. The pollutants directly polluted the drinking water source around the mine area, with an area of 28 km.

* Manuscript received March 13, 2019; revised April 22, 2020.
Corresponding author. Tel.:+8618810497363; *E-mail address*: kangjianqiao1990@163.com.
doi: 10.12720/sgce.9.4.820-825

Table 1. Groundwater quality before and after Honeymoon ISL in the United States [2]

| Value | pH | Mg/L | | | | | | | Bq/L | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Salinity | Na | Ca | Fe | $SO_4^{2}$ | Mo | $U_3O_8$ | $^{226}Ra$ | $^{222}Rn$ | $^{210}Pb$ |
| Pre-production mean value | 6.9 | 16100 | 4310 | 906 | 1 | 1754 | 0.013 | 1.2 | 205 | 5000 | 0.8 |
| Post production mean value | 2.2 | 16430 | 6170 | 940 | 260 | 5300 | 0.003 | 75 | 830 | 12700 | N.A |

Table 2 shows the analysis results of some elements in groundwater three years after the exploitation of a deposit in Xinjiang, China. As can be seen from Table 2, due to long-term infusion of leaching agent, the groundwater composition is significantly changed, resulting in excessive content of a variety of elements.

Table 2. Groundwater quality before and after ISL mining in the China [2]

| Value | pH | Mg/L | | | | | | Bq/L | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Fe | Pb | Mg | As | $SO_4^{2-}$ | U | $^{230}Th$ | $^{226}Ra$ | $^{222}Rn$ | $^{210}Pb$ |
| Post production mean value | 1.26 | 440 | 670 | 140 | 0.104 | 228 | 75 | 440 | 20.1 | 402.3 | 5.7 |

The main causes of pollution in ground leaching are the loss of technical solution caused by the damage of process facilities and the drilling and cleaning operations, spraying of solution caused by pumping water with an air lift, dregs and cores from drilling, the underground residual solution of the mining area and its loss to the adjacent overlying and underlying aquifers through the "window" of the aquifer. In the normal production process, there is still a certain concentration of the effluent of the adsorption tailings is also the cause of environmental pollution. The pollution sources in uranium leaching mainly include waste gas and waste water.

### *2.1. Waste gas*

The main waste gas from ground leaching is radon. In the process of in-situ leaching, radon associated with underground uranium mines is dissolved in the leaching solution under large ground pressure, and is extracted from the ground along with the leaching solution into the collection tank. As the pressure decreases, the gas and liquid rapidly separate and radon is rapidly released into the atmospheric environment around the sump.

Radon is a radioactive source with a short life (half-life is 3.82 d). Radon itself is harmless when inhaled. However, the daughter bodies produced by radon decay are all radioactive solid particles, which have three decay forms of α, β and γ. The three kinds of decay have different characteristics and different degrees of harm to human body. Among them, internal irradiation of α is the most harmful, because of its short range, it can be concentrated in a small area of the human body for intense internal irradiation, so that a small area of the body tissue to bear highly concentrated radiation energy and cause damage. For example, alpha particles in respiratory organs can be just in the range of the bombardment of the bronchial epithelial basal cell nucleus; can cause serious respiratory diseases, and even lung cancer.

### *2.2. Waste water*

The wastewater produced by In-situ leaching is mainly the sewage containing uranium, radium and other radioactive substances and other harmful substances to the environment. The causes of waste water pollution include the following aspects:

1) Leakage and drip. As leaching agent and leaching liquid are transported through pipelines and valves, the quality of pipeline connection and valve is directly related to the amount of pollutant loss.

2) External drainage. In general, in order to achieve the purpose of controlling the immersion range, the method of slightly larger volume of extraction than injection is often adopted. Therefore, during the water cycle, the water quantity is unbalanced, and part of the adsorbed tailings (still containing a small amount of uranium and a large number of other harmful substances) cannot be returned to the underground through the injection well and need to be drained out.

3) Loss of underground leaching liquid. In the normal production process, the loss of underground

leaching fluid can be reduced by effectively controlling the leaching range. However, if the leaching conditions change, such as: scale can affect the leaching liquid penetration speed and direction, for this change is not timely adjusted and controlled, the underground fluid flow turbulence, and near to the boundary of the liquid injection Wells, injection solution diffusion and osmosis, underground leaching liquid there will always be some inevitably flow to immersed boundary outside, cause pollution.

4) Extract during underground recovery. After the leaching, the groundwater and rock layers need to be treated to restore the contaminated groundwater to the acceptable state before leaching. During the recovery process, the residual leaching fluid in the ore layer needs to be extracted from the ground. It is also necessary to fully wash the ore bed with clean water, which is about 5 times more than the residual leaching liquid.

It can be seen that no matter what form of ground leaching wastewater is, if not treated, it will pollute the groundwater and surface water to a certain extent, causing the heavy metal ions such as Pb, U, Cu, Zn, Ni, Co, As and Cd in the groundwater and surface water to seriously exceed the standard. The concentration of $H^+$ and $SO_4^{2-}$ plasma in acid waste water is 20 times higher than that in normal condition. The infiltration of acidic water accelerates soil acidification, and strong acid anions ($SO_4^{2-}$) drive a large number of base cation leaching ($Ca^{2+}$, $Al^{3+}$, etc.), resulting in poor soil base nutrition, saturation of N and S in soil, decreased CEC in soil, and damage to local environment .The pollution of nearby natural water system not only affects food crops and aquatic organisms, but also does harm to the health of residents.

## 3. Environmental Protection Measures

### *3.1. Air protection measures*

The air medium in contact with the leaching stope and the leaching solution processing workshop is polluted by wind erosion and long-life radioactive aerosol in the contaminated production site and can be dispersed outside the production site by wind. All services, production buildings, dwellings and sites for socio-cultural activities should therefore be located in the upwind direction of the production site (taking into account the dominant direction). In addition, because the extracted leachate contains a large amount of radon, gas-liquid separation is required before entering the sump. The gas-liquid separation device should be set at the lower side of the prevailing wind direction of the well site. The protection requirements of the gas-liquid separation device are similar to the mine exhaust shaft. The liquid collection tank should adopt a curved structure, and the leaching liquid will flow into the collection pump tank. The sump pump tank is set upwind of the sump tank, and the leaching liquid is strictly prohibited to enter the sump pump tank directly without going through the gas-liquid separation device. The operator control room shall be separated from the pump pool and the pump room shall be equipped with exhaust devices to reduce the radon content in the air of the pump room below the allowable level.

### *3.2. Protection of the soil surface*

In order to prevent the surface pollution of the wellsite, in addition to strictly prevent leakage, but also need to take necessary measures on the topsoil around the wellhead. For example, before ground leaching, carry away the topsoil at the wellhead, and build a small pool around the wellhead to store the leakage solution, so as to prevent the leakage solution from infiltrating into the surface topsoil; After the leaching, the contaminated topsoil was buried in special pits and ditches, and the topsoil without pollution was used to restore the topography around the wellhead.

In order to prevent the stope solution from flowing to the surface, lime and reinforcement materials should be placed in advance to neutralize the leaked solution, and the ground at the leakage site should be strengthened and buried. All processing boreholes shall be provided with water intakes to prevent solution loss. The external drainage during drilling cleaning and testing shall be installed in a special container to return to the drilling hole. Where the soil is poorly developed, the contaminated layer can be removed and buried. In regions where the soil has utilization value, the soil within the range of 5m on both sides of the processing hole profile and 3m on both sides of each infusion pipeline should be stowed aside after 0.5m deep excavation and backfilled after mining. At the end of the mining operation, all the above sections are restored and soil is turned loose. The original structure of the soil can be restored after a cultivation period. Waste equipment and materials will be transported to the open pit and buried, which can help to eliminate the source of pollution.

### *3.3. Surface water protection measures*

In order to protect surface water, corresponding engineering buildings should be set up, such as mountain, ditch, protective ditch, dam, aqueduct, crossing passage, etc. The flood water, snowmelt water and rainstorm water should be diverted systematically to protect process equipment and pipeline. If there is a permanent surface water body within the mining zone, water quality detection points should be set, which are distributed in three zones: within the mining area, near the mining area and near the regional detection point.

The sedimentation tank of leach liquor containing precipitated suspended substance should be regarded as polluted water body. If the content of useful components in the sediments meets the industrial requirements and cannot be treated for a time, it shall be stored in situ.

In the initial stage of ground leaching, the effluent adsorbed from the production process can be injected into the next section to be mined or leached in combination with the mining sequence. For the adsorbed tailings that cannot be returned to the ground through the injection well, the harmful components in the tailings can be treated and then discharged through lime precipitation, ion exchange, constructed wetland, microbial treatment method and so on, so as to reduce environmental pollution.

### *3.4. Groundwater protection measures*

The groundwater is mainly contaminated by leach liquor in the ore-bearing aquifer. Because the in-situ leaching uranium deposit is located between the impermeable top and bottom plates, and the movement of the leach liquor in the vertical direction is limited to the ore-bearing aquifer. What’s more, the in-situ leaching process is closed, so the groundwater protection mainly includes prevention and control of groundwater contamination and groundwater quality restoration and treatment.

#### *3.4.1. Prevention and control of groundwater pollution*

Groundwater management and surface reclamation is an expensive work. Therefore, in the process of in-situ leaching production, it is better to sacrifice recovery rate and limit industrial development to ensure that groundwater resources are not polluted or less polluted. The methods of prevention and control of groundwater pollution mainly include selecting leaching agent with little underground pollution and controlling leaching range [3], [4].

1) Leaching agents with little pollution to groundwater should be used as far as possible, such as neutral $HCO_3^-$. And leaching with microorganism and few reagents are also effective. Although these methods with longer leaching time and lower recovery rate are not as efficient as leaching with acid, in the long run, they have a less impact on groundwater and surrounding rocks and are easier to control.

2) During the beginning of design and construction of mines, consideration should be given to the aspects causing pollution and treatment measures in the future. The leaching agent should be controlled not to flow outside the scope of the mining unit and the upper and lower aquifer outside the ore-bearing aquifer. The design of the pumping volume is 1 % ~ 3 % larger than the injection volume. The amount of pumping volume and injection volume can be controlled by effectively adjusting the amount of liquid and pressure.

3) The computer simulation methods can be used to simulate the leaching range and guide the well type design, which can help to narrow the diffusion range of the leaching solution and control the contaminated area. Monitoring well logging is established along the direction of groundwater flow to detect and forecast the leakage in time. Building a hydraulic barrier to prevent cross contamination between the leaching agent and the surrounding underground water system.

### *3.4.2. Restoration and treatment of groundwater quality*

The methods for recovering groundwater quality in in-situ leaching include distillation, electrodialysis, reverse osmosis membrane method, reagent precipitation, ion exchange, freezing method, deep burial method, and geochemical de-mining method [5]. Among all the methods, the geochemical de-mining method is low in cost and other methods are more expensive to implement. In addition to the above methods, electroadsorption is essentially an irreversible combination between the contaminated components and the clay interlayer in the water-bearing layer, and the contaminated solution (residual liquid and flushing liquid) moves towards clay under the action of electroosmosis when direct current is applied [6].

Regardless of the treatment method, the ultimate goal is to restore the affected groundwater as close to the pre-leaching background level with the best available technology. It is necessary to undertake spot investigation firstly before management and make economic and reasonable evaluation with the combination technologies. The recovery of groundwater quality usually takes 4 steps [7].

1) Pumping the groundwater from the ore bed. An immersible pump or compressed air is used to pump out the contaminated groundwater from the ore bed, while the clean water surrounding the ore bed enters to replace the contaminated groundwater. The pumping volume of groundwater is 1-3 ore layers and the extracted contaminated water can only be discharged after recovery and treatment.

2) Water purification [8-9]. Pumping the groundwater with 2-6 ore layers sequentially and treating it in a special water treatment device ensure all components in the solution can reach or approach the basic standard value of groundwater before in-situ leaching, and then return the treated water to the underground. It is strictly required to avoid repeated treatment of ground water due to non-compliance and extend the recovery time of ground water.

3) Injection of reducing agent. In the process of in-situ leaching, the ore layer is changed from reduced state to oxidation state due to the addition of oxidizing agent. If the layer remains oxidized and the remaining uranium and other metals remain soluble, groundwater will continue to be contaminated. In order to solve this problem, the seam must be restored to its original state. Appropriate reductants, such as hydrogen sulfide or sodium sulfide solutions, are used to inject into the aquifer, causing dissolved uranium and other metals to precipitate and stabilizing the groundwater composition into an acceptable level.

4) Water cycle [10]. The simple cycle of extraction and injection is carried out with the groundwater outside the ore body with the pore volume of 1-2 ore layers to homogenize the water quality around all drilling Wells. This measure can help to reduce the spatial and temporal instability of water quality during 6-12 months of monitoring. The rehabilitation will not be completed until a period of stabilization has proved that the ore-bearing aquifer is equivalent to the original water quality or has reached an acceptable level. At least 3-5 years observation period is needed after the restoration to determine the effect.

## Conflict of Interest

The authors declare no conflict of interest.

## Author Contributions

Kang Jian Qiao and Li Zhao Kun conducted the research, collected the literature and wrote the paper; Deng Hui Dong and Deng Jin Xun verified the data of the paper; Ma Jia proofread the details. All authors had approved the final version.

## References

[1] Wang HF. *Technology and Practice of In-situ Leaching for Uranium Mining*. Beijing: Atomic Energy Press, 1998.

[2] Sun B. Environment protection during uranium in-situ leaching. *Uranium Mining and Metallurgy*, 2008; (27): 142-145.

[3] Gavin MM. *Critical Review of Acid in Situ Leach Uranium Mining:1. USA and Australia*. Environ-mental Geology, 2001;

(41):401-404.

[4] Su XB. The present situation and development of green safety in China uranium mining. *Uranium Mining and Metallurgy*, 2017; (2): 119-125.

[5] Zhang XL. Discussion of prevention and treatment measures in groundwater pollution during uranium in-situ leaching. *China Population, Resources and Environment*, 2015; (S2):360-364.

[6] Wen JL. Water sampling technology for monitoring wells in uranium in-situ leaching. *Uranium Mining and Metallurgy,* 2018; (2): 147-153.

[7] Xu LC. Waste water treatment of $CO_2$+$O_2$ in-situ leaching uranium. *Uranium Mining and Metallurgy*, 2012; 31(2):96-99.

[8] Diao CN. Groundwater protection about in-situ leaching of uranium mines at a site. *Radioacive Protection Communication*, 2010;30(4):41-42.

[9] Jin XW. PhD dissertation. Construct risk assessment system of groundwater environment——A study of a historical heavy metal residue slag in Yunnan, China University of Geosciences, Wuhan, 2018.

[10] Liu CL. Risk assessment and control countermeasures of southern China's karst groudwater areal source pollution. *Acta Geoscientica Sinica,* 2017; 38(6): 910-918.