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Technical Note

Uranium Mining Techniques and Waste Management

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ABSTRACT
In this paper, mining techniques of uranium were investigated. Basically three type of mining techniques are applied. Basic mining techniques are underground mining, open pit or surface mining and in-situ leaching mining methods. Each of them has several advantages and disadvantages to the other. Specifications of each technique was evaluated in this study. Uranium mine wastes present the most significant waste management problem because of their large volume and their radioactivity. Most of the constituents in these radioactive wastes are found naturally in soils and bedrock. During the uranium mining and milling operations, natural radioactive material changes its chemical and physical form so that their potential for mobility is increased. The mobility results leakage to the environment and the public.

Keywords: uranium, mining, waste, management

INTRODUCTION

Uranium ores are typically associated with minerals in the parent rock. Controversy exists over the exact geological history that resulted in their formation, but the overall formation can be simply described as involving the transport of various metals in a positive oxidation state with hydrothermal or other effluents to a location where the groundwater had a lower redox potential. At this site, reactions occurred over time to lower the oxidation state of the metals and induce them to precipitate to form the ore body. The presence of sulphates or arsenates and their reduction to sulphides or arsenide led to the formation of metal sulphides. The chemistry of milling uranium-bearing ores involves dissolution and oxidation of the uranium, and subsequent uranium extraction from solution. Several steps are carried out in the milling of the ore. The first milling step commonly involves fine grinding to at least 50 percent minus 200 mesh, followed by leaching of uranium from the ore using either an acid leach (sulphuric acid) or an alkaline leach (sodium hydroxide and oxygen). The dissolving agents leach some of the reduced minerals and not others. With pyritic ores, for example, it is thought that only small quantities of pyrite are dissolved by proton attack in a hot sulphuric acid solution (WNA, 2020).

Release of radioactive constituents from radioactive uranium waste can occur by leaching of the radionuclides and discharge to the aqueous environment, erosion of dust from the tailings surface by wind and release of radon gas to the atmosphere. Environmental degradation can also occur because of increased acidity in receiving waters due to pyrite oxidation, and the release of toxic heavy metals, dissolved solids and environmentally active chemicals into groundwater supplies, lakes, and rivers. Appropriate management technique should be implemented to protect environment and the public.

MINING METHODS AND MATERIALS

Open Pit or Surface Mining

Open pit or surface mining is the removal of overburden to get at the ore below (**Figure 1**). Overburden is the rock and soil material, which is removed over the ore body. Uranium ore grades are in the range of 0.3-1.5%. Open pit mining is feasible if the uranium ore is less than 150 meters. Excavated overburden material generally stored as on-site nearby the open pit mine facility. Once the ore formation is appeared, benches are prepared to excavate the ore properly. In the open pit facility, benches are connected by roads for the transportation of material. Pumps are used to dewater the mine water from the pit (IAEA, 2010).

Advantages of open pit mining of uranium ore

Open pit mining is easier mining technique than underground mining. Because of open-air, this technique has better ventilation when compare to underground mining. Because of the strict national environmental regulations, a reclamation should be prepared. The reclamation plan covers

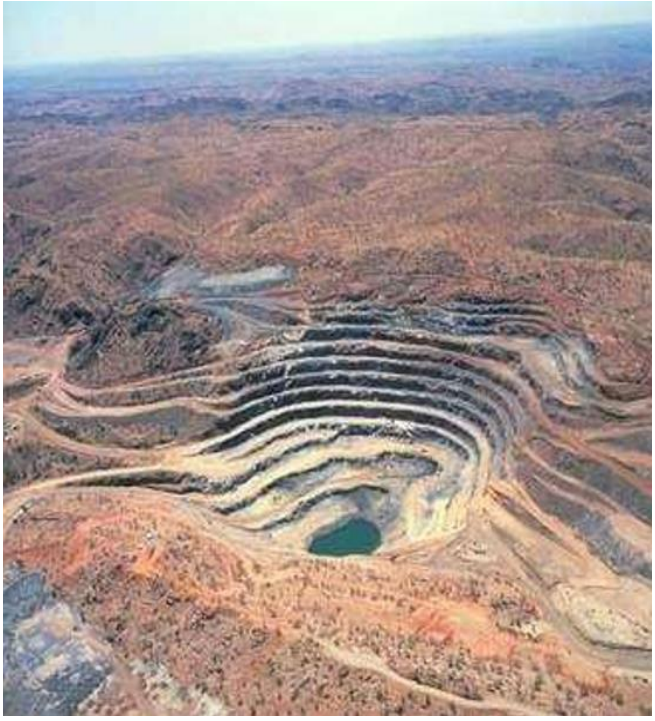

Figure 1. Open pit uranium mining

mining, backfill, and other measures to decrease the dimensions of the footprint on the landscape. Tailings piles have to be built on synthetic liners and have to be monitored by leak detection wells. Dust and radon control should be taken into account to satisfy working level requirements.

Disadvantages of open pit mining of uranium ore

When compare to other mining techniques surface mining has the biggest footprint. Enormous excavated waste rocks are stocked nearby the facility. Initially waste rock has not any environmental impact at the under surface but once excavated it is exposed to the atmosphere. In case of availability of sulfides in the rock, these piles become hazardous to the environment. In this case, remediation of these waste rock piles is extremely costly and time-consuming process. In addition, groundwater restoration to avoid contamination can be extremely costly. Dust and radon is another important issue to be taken into account for mineworkers' health.

Underground Mining

Underground mining technique is generally applied to excavate at higher concentrations of uranium especially if uranium formation is too deep to get at from open-pit. Shafts and production galleries are constructed and excavation is realized by drilling and blasting. The ore is transported to the surface for concentration (WNA, 2008).

Advantages of underground mining of uranium ore

Underground mining technique has a smaller surface footprint than surface mining. In addition underground mining produces less waste rock. Higher production levels can be ensured by advanced mining techniques such as robotic systems. Monitoring and ventilation systems generally sufficient to prevent radiation and to avoid radiation dosages for mineworkers.

Disadvantages of underground mining of uranium ore

This technique is much more expensive than other techniques. In addition, in case of any contamination or leakage to local aquifers, remediation of ground water is extremely expensive and time consuming. Common problems of underground mines are appeared because of insufficient ventilation and dust, radon and diesel fumes become a serious threat to miners' health.

Milling

Uranium formations generally include low-grade uranium host rocks which are less than <0.3%. These rocks are excavated, and uranium is concentrated at the milling facilities. Concentration process is start from crushing and grinding the rock into very fine paricles. Water is used to create concentration slurry. Lixiviant are used as acidic or alkaline solutions to receive the uranium from the host rock. Generally, up to 98% of the uranium can be gained from the uranium host rock. After this lixiviant solution, process uranium oxide is precipitated as yellowcake. At this stage, uranium concentrate is ready for enrichment. The yellowcake is transported to uranium enrichment facility. The remaining waste remains in slurry form, and it has to collect in a special waste pool. Therefore, the waste slurry pumped to a tailings dam. Environmental contamination risks of the uranium contamination should be taken into account from tailing dam.

Advantages of milling

Milling process is the worldwide common effective technique, which covers crushing, grinding pulverization and concentration of uranium ores.

Disadvantages of milling

Milling process generates tailings and has a potential to make hazard to the environment because of any remaining uranium or heavy metals leakage. Remediation of milling tailings is extremely expensive. Generally, porous raw materials are used as filters to remove water from the tailings slurry. Measures should be taken to protect ground water to avoid any contamination of uranium and heavy metals.

In-Situ Leach

In case of uranium ore formation lie in groundwater in porous formations (commonly gravel or sand) and may be removed uranium solution simply by dissolving the uranium and pumping it out. This method called as in-situ leach (ISL). ISL is the preferred method to extract uranium when compared to other techniques. Because this method is cheaper to receive the soluble ores out of the ground without any excavation. Environmental impacts are also very low when compared to other than traditional underground or open pit techniques (**Figure 2**).

In Australia and Kazakhstan ISL is implemented by using sulphuric acid and peroxide solutions and remediation has not been required. In the USA, alkaline solutions are preferred. In both techniques, the convenient lixiviant solution is used to dissolve uranium in the underground. The dissolved uranium migrates through the aquifer leaching the uranium bearing host rock. Then uranium-bearing solution pumps to the surface for further processing.

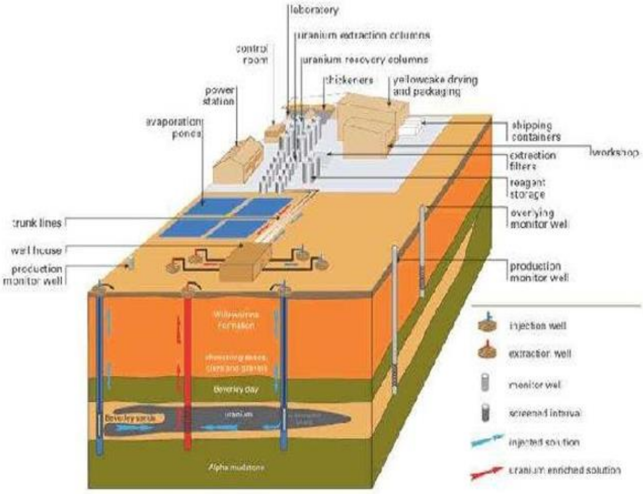

Figure 2. In-situ leaching of uranium mining

In ISL process, commonly some activators are used such as gaseous oxygen or bicarbonate is added to the lixiviant solution to make easier for uranium to go into solution. The pH of the solution is nearly neutral which is between 6.5 and 7.0. By this way, preliminary arranged lixiviant solution oxidizes the uranium in porous sandstones and make it easier to go into pump out solution.

Injection wells are drilled within a convenient wellfield pattern and the oxygen-rich solution is pumped down via injection wells. The lixiviant solution moves through the uranium host rock and dissolving the uranium in the ground. After this injection, the uranium bearing solution should be transferred to the surface by production wells. These injections pump uranium-enriched ground waters to the surface. Monitoring wells should be drilled surrounding these wells to check on breakthrough of uranium-and mineral-enriched waters. These uranium bearing waters are pumped out to the surface and filtered to remove the uranium, and the treated waters are refreshed with oxidant and carbonates and sent back down well to start the process again (Locke, 2012).

Advantages of ISR

This method leaves comparatively small surface footprint and small amount of waste rock created only during the drilling the wells. In addition, it has inexpensive start-up cost. Environmental point of view it is less expensive to remediate than traditional mining and milling operations and cause less radiation exposure for the workers.

Disadvantages of ISR

Main disadvantage is it has possible local contamination of aquifers. Any contamination at monitoring wells should be checked regularly. Wastewater has to be collected in a convenient isolated pool properly.

WASTE MANAGEMENT METHODS

In uranium, mining industry enormous quantities of rock and liquid waste are generated. Majority of these wastes include toxic radionuclides Ra-226 and Rn-222.

Mining

Although the waste rocks have not any radioactivity of any significance, these wastes also need proper management. These types of rock wastes not only used for backfilling of mines, but also used for the construction of the mine site, roads, buildings, facilities, etc. as well. If these type of waste rocks is used for building, then the responsible authority controls that any resulting radiation exposures of the public will remain within acceptable limits. In case of waste rocks contain various concentrations of radionuclides above than the acceptable radiation limits; they must be managed properly. Seepage from waste rock piles must be collected and treated in waste management program. After treatment or clean wastewater can be reused in the mine and the mill. Mine water should be checked if any uranium, thorium, radium, or other metals available in solution it would increase radiation levels in underground mine and air. Wastewater is collected in an appropriate pool or held in a waste retention system. Excess water can be discharged under controlled conditions to surface waters. In underground uranium mines, exhaust air from the ventilation system is contaminated with radioactive gases, and ore dust, rock-dust, and fumes. This exhaust air should be monitored and treated, if necessary, before released into atmosphere. By this way, unacceptable levels of radon or dust make no further hazard on the public.

Milling

In the milling process, host rock mineralogical properties and the extraction process require some modifications in the waste management system. Because generally uranium-bearing minerals are soft and comprise the bulk of the gangue by reducing to slimes and mixed with clays. The handling of this slime of the ore is difficult in waste management processes. Acid leaching is generally adopted if the uranium ore does not contain a high proportion of limestone or other gangue material suitable for alkaline refining. If there is pyrite in the mine deposits, this acid creates a big waste management problem as it will create mine drainage. With the presence of pyrite, sulfuric acid and wastes producing high concentrations of sulfate are gradually oxidized. If other heavy metals exist in the environment as sulfides, which can be oxidized and leached from sediments, acid enhances the effectiveness of mine drainage. Generally, the reusability of saline solutions obtained from alkaline leaching process is high. The water slurry is widely used to transport the washed leached waste that will contain various chemicals such as carbonates, sulfates, and nitrates. Barren solutions from acid leaching are similarly used for waste handling and contain higher concentrations of contaminants, including sulfuric acid, heavy metals, nitrates, sulfates, amines, and chlorides. The major radionuclides usually found in these solutions are Th-230, Ra-226, Rn-222 and Pb-210, the most critical of which are Ra-226. Reuse, control, and reduction of water use is the most effective way to reduce the volume of waste solutions. In the treatment phase of acid mill waste from the plant, lime or a combination of limestone and lime is neutralized to alkaline pH, which is generally followed by salt of long chain fatty acid process. It is possible to reduce these leaks with adequate engineering of the Waste containment system. Where it occurs for this, this waste solution can be pumped back into the system or reprocessed with the discharge liquid. However, continuous and long-term control of the leak is required. On the other hand, dry ore dusts from processes in the ore preparation plant, fumes from acid processes, airborne pollutants in the "yellow cake" are processed by traditional cycle methods such as dust removal, cyclones, and electrostatic precipitation. Although the radon released during the milling phase in the plant is difficult to remove, it can be safely processed with a suitable exhaust design.

Tailings

Mill wastes from the mineral processing facility are solid residues and related liquids that remain after uranium is extracted from the ore, and contain radioactive and non-radioactive materials. Solid wastes, on the other hand, consist mainly of the finely ground mass of the original ore and various chemicals precipitated from the waste liquids. The waste from this facility is pumped as a waste slurry to a waste containment system where solids settle and accumulate. The main purpose of the waste containment system is to maintain the physical and chemical stability of these wastes (Abdelouas, 2006).

RESULTS AND DISCUSSION

Mainly three mining techniques are used for uranium mining. Each of these techniques has its own requirements depending on geological and ore specifications for implementation. Waste types and amounts are changing depending on mining technique. Each uranium mining techniques has to be evaluated not only related to its general advantages and disadvantages, but also site-specific conditions should be taken into account as well. Waste management techniques also depend on the waste types and waste amounts.

CONCLUSION

The uranium mine wastes could adversely affect the public and the environment in several potential ways. In the environmental point of view, radioactive constituents in these wastes and their possible release to the environment are currently of greatest concern.

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