

URANIUM MINING BY IN-SITU LEACHING

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INTRODUCTION:

Uranium is commonly understood as a material storing a huge energy and its only commercial application is as nuclear fuel. But apart from its uses in nuclear power plants, the possibility of its use in nuclear weapons makes the material of strategic importance and thereby, restricting its free global trade. The growth of uranium mining normally follows the pattern of growth nuclear power generation capacity.

In India, the Government is committed to appreciable increase in contribution of nuclear power to the total power generation capacity and it has been felt that a balance mix of hydel, coal and nuclear power is a must for meeting the long term power requirement of agricultural and industrial sector. Hence, as a primary fuel for the nuclear power plants of the country, uranium occupies a special standing and this necessitates the call for extraction of this rare element from all available sources with cost effective, innovative methods.

Natural occurrence of uranium – The element uranium is very widely distributed throughout the crust of earth. Almost all types of rocks contain some amount of uranium. Acid igneous rocks like granites, syenites etc are rich in uranium, whereas basic and ultrabasic rocks are depleted of uranium. Uranium is also present in river water, ground water and even in seawater. But, the common source of uranium for mankind is the rocks, though it is also extracted from seawater in some countries. In spite of this ubiquitous nature of uranium, the rich uranium deposits are very rare on earth.

In nature, uranium ions normally occur in tetravalent and hexavalent form. In hexavalent state, it is easily soluble in acidic water. Chemically, metallic uranium is highly reactive. It can be leached in acidic or alkaline environment. The properties of uranium, particularly its solubility, ease of transport and precipitation, have led to the formation of ore deposits of a number of types in a variety of geological settings. These deposits can be formed at the surface, at low temperature in recent environments or in deep seated older formations.

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A number of such deposits are of economic significance as sources of uranium. On the basis of occurrences in favourable geological environments, the world uranium deposits are classified as follows.

1. Quartz-pebble conglomerate and arenites type – as disseminations in conglomerate associated with gold (Au > U)
2. Vein type (structure and lithology controlled) – mineralisation in shears or fractures
3. Unconformity related type – as disseminated to massive in tabular or lenticular horizons
4. Sandstone type – as dissemination in arkosic sediments, flat lying
5. Magmatic disseminated type -
6. Phosphoritic type – syngenetic uranium in phosphatic sediments
7. Surficial disseminated type – uranyl minerals as disseminations in sediments

In India, uranium occurrences of almost all the above types are reported in different parts of the country.(Fig.1)

Occurrence of uranium in the above types call for application of conventional mining methods like open pit mining or underground mining and subsequent extraction by hydro-metallurgical process. But, sometimes the occurrence of uranium in sandstone provide an opportunity to recover the metal in an innovative method of extraction called IN-SITU LEACHING, **provided** some necessary geological and geo-technical conditions are met.

IN-SITU LEACHING:

The technique of in-situ leaching is a relatively unknown method in India, though it is largely practiced and successfully implemented in almost all mineral-rich countries of the world. Extraction in this method is accomplished through the dissolution of natural in-place metal in underground and recovery of the leached solution from underground for further processing. This is achieved by introducing a suitable solvent liquid into the ore body through the wells, allowing the liquid to pass through the ore body for desired period so as to dissolve the metal and finally recovering the pregnant liquor through other wells. (Fig. 2)

The technique, wherever properly implemented has resulted in good recovery of the metal that compares well with the recovery in conventional methods. About 15-18% of world's uranium production is presently met by ISL industries, which is expected to go up to 20% by the year 2015. At present, there are about 98 ISL well fields for uranium in operation all over the world and about 8 sites are under construction or expansion. It

may also be noted that more than 50% of US's uranium production come from ISL well fields against about 15% obtained by the conventional mining methods.

CONDITIONS FOR IN-SITU LEACHING

Certain geological and hydrological criteria must also be met before an ore body / deposit is considered suitable for in-situ leaching.

1. The ore should occur in a generally horizontal bed underlain and overlain by a relatively impermeable stratum.
2. The host rock should have a good permeability.
3. The ore must be located below the water table.
4. The direction and velocity of regional water flow must be known.
5. The uranium minerals in the ore body must be amenable to proposed dissolution process preferably with carbonate solutions or relatively mild reagents.
6. The ore should occur at favorable depth.
7. The ore body should be of sufficient size and grade to justify the cost of production.

TECHNIQUE OF IN-SITU LEACHING:

Under favourable geological-hydrogeological conditions, the process of in-situ leaching is carried out by injecting the suitable solvent into the orebody through injection holes. The solvent is allowed to pass / flow through the ore body for desired period dissolving the desired metal content and the pregnant solution is then recovered through production well by pumping.(Fig.3). The pumped out solution pass through normal hydrometallurgical route in which uranium is segregated.

Commercial operation of an ISL method involves following construction activities.

A. WELLFIELD DESIGN AND CONSTRUCTION:

Design of the well fields in ISL is based on known geology and hydrology, assisted by computer modelling techniques.

A typical ISL operation normally has four different types of wells / holes.

- a) Injection well - Through this well, leachant is injected into the ore body at desired depth(s).
- b) Recovery / Production well - Through this, pregnant solution from underground is pumped out and sent to the mill for further recovery.
- c) Monitor well - These wells are used to know the degree of contamination of ground water, if any.

d) Liquidated wells - In a typical ISL well field map, these wells are found distributed throughout the area. These are generally the exploration or other miscellaneous holes which were drilled to prove the ore body, but later on sealed / grouted / liquidated with high viscosity bentonitic mud. These sealing of unwanted holes are an absolute must to maintain aquifer isolation in an ISL operation.

Normally, the well field design is based on five spot or hexagonal pattern where the injection wells are located at the corners. Production wells are placed at the center of the pattern. The main objective of the pattern design is to maximise the ore reserve addressed by each well within the operating spacing limitations. Factors like permeability and rate of leaching etc. are also considered in deciding the pattern.(Fig.4, 5 & 6)

After the completion of preliminary design, the delineation drilling / well completion stage begins. All planned wells are drilled initially with a 5.25inch (133 millimeters) drill bit. Construction procedures for injection well and production well are almost same. These wells are normally 150mm diameter, drilled little beyond the bottom of the mineralized zone. 120mm outer dia PVC pipes are placed inside the hole joined together by a special gum or with tap screws or thread joints. PVC filters of the same size with 1mm slot are placed inside the well across the ore zone. The space between the PVC pipe and the well wall is grouted or packed with sand or gravel from bottom to top leaving the selected ore zone. Then the holes are stimulated using a process called air lifting. (Fig.7)

Both injection well and recovery well are mutually reversible. In recovery well a submersible pump (2-10 Hp) is placed just above the ore zone to pump out leached out solution to the surface. Each well while in operation is provided with a flow meter, pressure gauge and necessary valving for pressure release etc. Individual lines from the recovery wells enter into the plant on one side and injection wells on the other side. The wells and the plant are designed to be versatile enough to allow the individual wells to be changed from injection to production and production to injection as changes in the well field operation may require.

Monitor wells are installed in the periphery of the deposit about 300m away from the outer line of operating wells. These assist in 'excursion' detection in the event of horizontal or vertical migration of the mining fluids. A rise in water level in these wells indicates a build-up of water presence within the area requiring more withdrawal from the production well while a fall in level indicates too high a withdrawal rate. A proper input-output balance may thus be obtained to minimise solution losses.

B. SELECTION OF SOLVENT AND OPERATION:

Selection of solvent / lixiviant along with oxidant / reductant is a very important factor which needs very careful consideration of mineralogical factors. The most important of them are -

- a) Type of mineralisation and correlation of soluble and insoluble minerals.
- b) Type of minerals and associated mineral integration which determine the access of the reagent to minerals' surface.

Lixiviant is distributed to injection wells through water flow meters installed on distribution manifold which totalise daily injection. Likewise flow meters are also installed on production wells. When the charged lixiviant begins to flow through the formation, the dissolved oxidant oxidises the minerals coating the sand grain and the element goes into solution. The solution flows towards the production well where it is pumped to the surface and then to the plant for stripping of the element in conventional extraction process. The depleted process water is again charged with oxidant and returned to the wellfield for reuse.

C. ENVIRONMENTAL AND SAFETY CONSIDERATIONS:

Although in-situ leaching system is an enclosed process, involving little contact with the mining solutions is very harmful. Hence, the primary environmental considerations for in-situ mining are associated with

- a) The control of lixiviant during mining.
- b) The restoring of aquifer back to usable conditions after mining.

Several measures are followed to eliminate the potential problem of lixiviant migration away from the well field. By recovering more than is injected, a cone of depression around each recovery well is created which results in developing a gradient towards the well field. This makes the tendency of the native ground water to move inwards rather than lixiviant moving out.

A series of monitor wells are installed within the host rock completely encircling the planned leach area. These monitor wells are sampled regularly during operation and analysed for chemical indicative of lixiviant to ensure that no leach solutions migrate beyond the mining area or vertically into overlying or underlying aquifers.

At the end of mining in a particular well field, several chemical parameters of the pre-mining ground water quality will be left elevated before baseline conditions. Reducing these elevated chemical parameters in the ground water to a condition similar to

background or baseline condition is the overall objective of the restoration plan. This is normally achieved in two ways.

Groundwater sweep - It is the initial step in the restoration of the unit. The method consists of pumping from the wellfield recovery wells with no reinjection, resulting in the a total withdrawal of existing lixiviant. The groundwater sweep lowers the total dissolved solids (TDS). Groundwater sweep is typically limited by the amount of groundwater that can be removed on a continuous basis. The removal of one pore volume through the sweep normally pulls out all lixiviant out of the wellfield.

Water treatment with reverse osmosis - This is the second phase of restoration where wellfield solutions are treated with reverse osmosis and reinjected back to aquifer. The reverse osmosis unit is quite effective at lowering metals and overall TDS concentrations. Solution coming from the well field is treated to lower the pH, then sent through reverse osmosis unit where the water is filtered through cellulose acetate membrane under pressure. This clean water is then reinjected back to the well field for restoration of aquifer.

If pre-mining water quality cannot be achieved by a combination of groundwater sweep and reverse osmosis, a reductant such as hydrogen sulphide may be injected into the aquifer to create strong reducing conditions which immobilises remaining contaminants. Addition of sodium sulphide during restoration is also an alternative to direct injection of hydrogen sulphide.

RECOVERY OF METALS:

Recovery of in-place reserves varies widely even within patterns in the same wellfield. Geology, mechanical problems and the quality of ore reserve estimations can all affect recovery of in-place reserves. However, in US, uranium producers report average recoveries of 70-80% of in-place uranium through out their operations and this is normally achieved in 3-5 years of continuous operation of the deposit. But sometimes very high recovery have been reported which has been attributed due mainly to the

- a) narrow width of the orebody
- b) consequent low reliability of the ore reserve computation
- c) normal oversweep of the lixiviant to below cut-off ore.

It has been generally agreed that recovery degree at in-situ sites is lower than at a hydro-metallurgical plant by 15-20%. But considering the loss in conventional mining and obtaining some additional quantities from the off-grade and low-grade reserve, the total recovery approximates and sometimes exceeds the level of the traditional mining and subsequent hydro-metallurgical extraction.

ADVANTAGES OF IN-SITU LEACHING:

There are several advantages of recovering metals from an ore deposit in-situ over conventional mining methods. These include -

1. The method has the potential to work deposits confined to unfavorable horizons like incompetent host rock, poor ground conditions or large water inflows.
2. It is feasible in this method to work deposits with poor to off-grade ores, which are uneconomical to extract by traditional mining methods.
3. Shorter period of putting the deposit into operation.
4. Environmental damage to the mine site is reduced because
 - a) Surface disturbance is minimised because of automation of mining process underground.
 - b) Large quantities of rocks and tailing are not to be disposed on surface.
5. Risk of mining personnel working below the ground is eliminated.
6. Very little risk of exposure of personnel to radiation
7. Better economic and technical indices of deposits working because of
 - a) lower capital cost
 - b) less manpower
 - c) high productivity
 - d) quicker return on investment.

CONCLUSION:

After a modest but positive growth of nuclear power generation in the country during last three decades, the country is now set to achieve an ambitious target of 20000 Mwe by the year 2020. Presently, India's uranium requirement for the nuclear power programme is fully met by the production of uranium ore from three underground uranium mines operated by Uranium Corporation of India Ltd under the administrative control of Department of Atomic Energy. These mines are located in Singhbhum Thrust Belt, Bihar.

Recently, a few sandstone type uranium deposits have been discovered in the North-eastern part of the country. These deposits lie in thick pile of Upper Cretaceous and Tertiary sediments lying over the basement granite and are being assessed for exploitation by different methods. The technique of application of in-situ leaching in this area is also under consideration for which various laboratory tests are being taken up. With steady implementation of country's nuclear power programme, the demand for large production of uranium at competitive cost may rise over the years. On favourable geologic and hydrologic conditions, some of the low-grade occurrences in North-Eastern States may find favour for In-situ leaching due to inherent advantages of the system like low gestation period, low cost technology, low operating cost and potential for adjusting the production to match the requirement.

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REFERENCES:

1. "Metallogenesis of uranium deposits" - Proceedings of IAEA Technical committee meeting, 1987.
2. "In-situ leaching of uranium: Technical, Environmental and economic aspects" - Proceedings of IAEA Technical Committee meeting, 1987.
3. "Uranium in In-situ Leaching" - Proceedings of IAEA Technical Committee meeting, 1993.
4. "In-situ Leach Uranium Mining" - IAEA Technical Committee meeting, 1996.
5. Internal report of UCIL on uranium findings

LIST OF DRAWINGS ENCLOSED:

- Fig. 1. Uranium occurrences in India.
- Fig.2. Principle of in-situ leaching
- Fig.3. Flow pattern in in-situ leaching
- Fig.4 & 5 Well design pattern.
- Fig.6. A typical ISL well field
- Fig.7. Cross section of injection / production well