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EMERGING TREND OF URANIUM MINING: THE INDIAN SCENARIO

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Abstract. From the modest beginning in 1948, the atomic energy programme of India has grown to vast dimensions with mosaic of many interrelated programmes. The uranium ore mining and processing industry of the country began at Jaduguda in 1968. It has made a very impressive growth during these years with four operating mines and meeting the entire fuel requirement of the country. The country now has a definite plan for multi-phase expansion of the nuclear power programme, self-reliance of raw materials being the basic drive. The uranium mining industry is fully geared up to meet the challenge of uranium fuel demand by undertaking uranium mining and processing activity progressively in line with the requirement of fuel. Several new uranium ore mining projects are in pipeline for execution. The technology of mining, processing and tailings disposal has also undergone improvement absorbing global advancements in these fields.

1. Introduction

Soon after independence, with the formation of Atomic Energy Commission in 1948 India made a humble beginning of its inspiring atomic energy programme. Consequent to this development, it was felt that the country must have indigenous resources of basic raw materials such as uranium, thorium etc. A group called Rare Metal Survey Unit (later on renamed as Atomic Minerals Directorate for Exploration and Research) was formed by Govt. of India to locate good uranium deposits in the country. During that period, the emphasis of search was laid on the existing mineral belts and geologically favourable areas of the sub-continent. Association of uranium with copper and gold was already known in some parts of the world. On this analogy, known copper and gold provinces of the country were extensively investigated. The pioneering work of the first group of geologists, brought to light many uranium occurrences in Singhbhum Thrust belt in the eastern part of the country and soon it became evident that this belt holds the potential for commercial uranium mining operations.

2. Uranium deposits of India

Jaduguda in Singhbhum Thrust Belt (in the state of Jharkhand, formerly part of Bihar) is the first uranium deposit to be discovered in the country in 1951. The Singhbhum Thrust Belt (also known as Singhbhum Copper belt or Singhbhum shear Zone) is a zone of intense shearing and deep tectonization with less than 1km width and known for a number of copper deposits with associated nickel, molybdenum, bismuth, gold, silver etc. It extends in the shape of an arc for a length of about 160 km.

This discovery of uranium at Jaduguda in this belt paved the way for intensive exploration work and soon a few more deposits were brought to light in this area. Some of these deposits like Bhatin, Narwapahar and Turamdih are well known uranium mines of the country. other deposits like Bagjata, Banduhurang and Mohuldih are being taken up for commercial mining operations. Some of the other areas like Garadih, Kanyaluka, Nimdih and Nandup in this belt are also known to contain limited reserves with poor grades.[1]

Apart from discoveries in the Singhbhum Thrust Belt, several uranium occurrences have also been found in Cuddapah basin of Andhra Pradesh. These include Lambapur-Peddagattu, Chitrial, Kuppunuru, Tumallapalle, Rachakuntapalle which have significantly contributed towards the uranium reserve base of India. In the Mahadek basin of Meghalaya in North-Eastern part of the country, sandsyone type uranium deposits like Domiasiat, Wahkhyn, Mawsynram provide near-surface flat orebodies amenable to commercial operations. Other areas in Rajsthan, Karnataka and Chattishgarh hold promise for developing into some major deposits. (Fig.1).

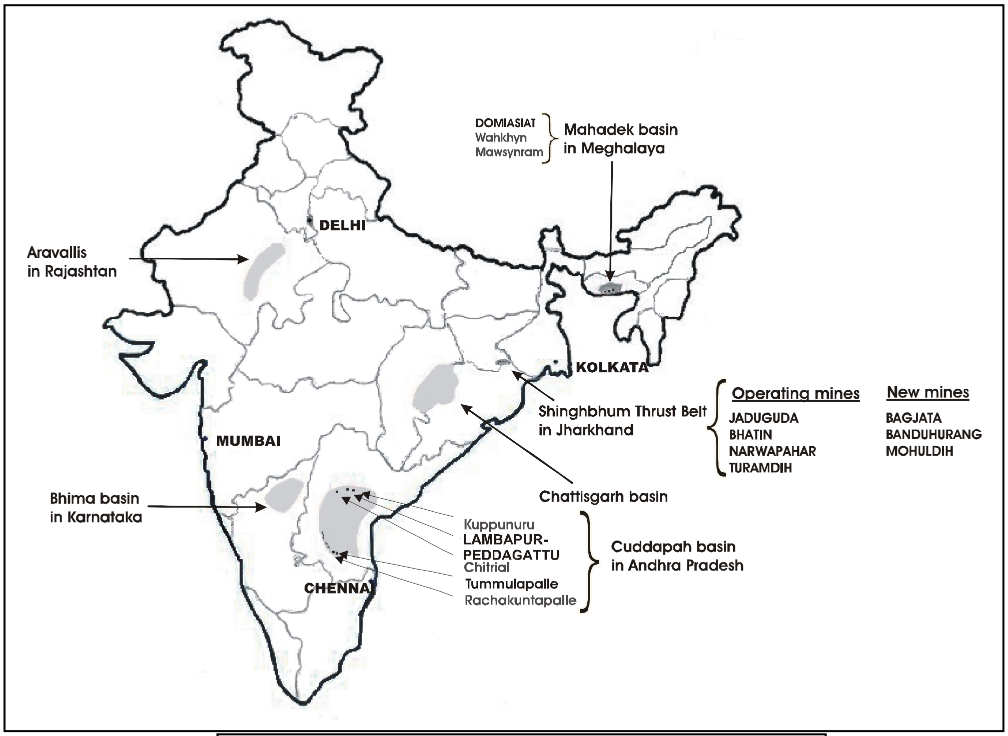


Fig. 1. **Major uranium provinces of India**

3. Uranium mining in India

The uranium mining in India made an exciting beginning with the formation of Uranium Corporation of India Ltd. in 1967 under the Department of Atomic Energy. Since then, the uranium industry of the country has recorded phenomenal growth in production and up-gradation of technology. The corporation launched its operation with the commissioning of an underground mine and ore processing plant at Jaduguda (1968). Subsequently, underground mines at Bhatin (1987), Narwapahar (1995) and Turamdih (2003) were commissioned. All these units are within 25 km from Jaduguda in the state of Jharkhand. The process plant at Jaduguda was progressively expanded embracing newer technologies to treat additional ore generated from the new mines.

Keeping in view the nation’s endeavour to expand nuclear energy infrastructure (20,000 MWe by 2020 AD from the present capacity of 2770 MWe), new uranium mines are being opened by UCIL not only in the Singhbhum Thrust Belt of Jharkhand but also in other parts of the country.

3.1. Operating mines

Jaduguda Mine: Jaduguda is the first mine in the country to produce uranium ore in a commercial scale. In this deposit, two parallel lodes extend from surface up to a depth of 905 m, which may also persist deeper. The mineralization is structurally controlled being confined to shears. The entry into the mine is through a vertical shaft of 640 m deep, which was sunk in two stages - from surface to 315 m and then from 315 m to 640 m. The mine has been further deepened by sinking an underground vertical shaft from a depth of 555 m to 905 m. Both the shafts are equipped with two tower mounted multi-rope friction winders - the Cage winder and the Skip winder. Double deck cages are used for movement of men and material and for hoisting of waste rock. Skips with a payload of 5 tonne are used for hoisting of ore. Levels are generally developed at vertical intervals of 65 meters. The principal stoping method adopted in Jaduguda Mine is horizontal cut-and-fill using de-slimed mill tailing as the fill. Jaduguda mine is presently the deepest operating mine of the country. [2].

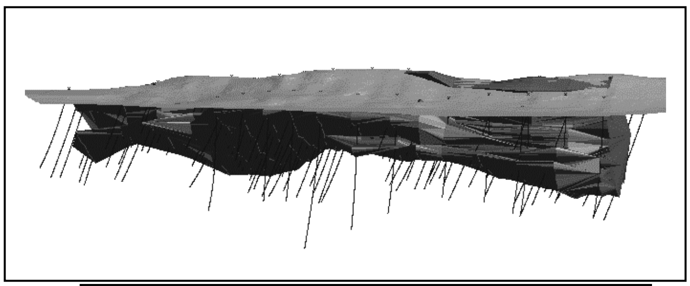
Bhatin Mine: Bhatin is a small uranium deposit situated 3 km west of Jaduguda. Geological settings, mineral assemblages and other host rock characteristics in this deposit are similar to those of Jadugdua deposit. The mine is now 215 m deep. The entry into the mine is through adits. The lower levels are accessed by two principal winzes and are equipped with double drum winders with provision for man winding. The levels are developed at 50 m interval. The stoping method is similar to that of Jaduguda. As the ore body is narrow, only pneumatic equipment are used for stoping and development work. Ore from Bhatin mine is transported by road to Jaduguda for processing and the de-slimed tailings of Jaduguda mill is sent back for mine back-filling. Mine deepening at Bhatin has now been taken up to create additional production levels.

Narwapahar Mine: It is a large deposit located 12 km west of Jaduguda. This mine was commissioned in 1995. A 7^0 decline has been developed as entry to the mine in the footwall side of the ore body through which large machinery move underground. From the decline, ramps are developed as entry to the stopes at different elevations, which facilitates the movement of twin-boom drill jumbo, low-profile-dump-truck, service truck, passenger carrier, low profile grader, scissor-lift etc. This system of mining has effected early commissioning of the mine with high productivity and low mining cost. It has also provided the flexibility to adopt different stoping methods that becomes suitable due to the variations in width and inclination of the ore lenses. Movement of men and hoisting of ore from deeper levels is done through a vertical shaft sunk up to a depth of 355 m. Cut-and-fill is the principal stoping method adopted in Narwapahar mine. Ore from this mine is sent to Jaduguda by road for processing. The de-slimed mill tailings of Jauguda mill and the waste generated from the mine are used as the filling material. The split ventilation system, micro-processor based bulk ore assaying system with automatic grade estimation and subsequent computation are some distinctive features in this mine. [3]

Turamdih mine: Turamdih uranium deposit is located about 24 km west of Jaduguda. The entry into the mine has been established through a 8^0 decline which provides facilities for using trackless mining equipment like passenger carrier, drill jumbo, low-profile dump truck etc. At a depth of 70 m (first level), the ore body has been accessed from the decline by a cross-cut. Drives are being developed following the contacts of ore body. Ventilation shafts have been sunk in line with the requirement of adequate fresh air. The development faces are ventilated by auxiliary ventilation system using auxiliary fans and flexible ducts. A vertical shaft of 5 m diameter is being sunk from surface up to a depth 250 m with facilities for ore hoisting and movement of men and material. The ore from this mine will be processed in the new plant, which is under construction near the mine site at Turamdih.

3.2. New mines in the state of Jharkhand

Banduhurang mine: This deposit is the western extension of Turamdih mineralization, where part of the ore body outcrops at surface. It is a low-grade, large tonnage deposit. After the initial evaluation, the techniques of computerised ore body modeling and mine planning using SURPAC software was carried out. Open-pit mining method has been considered as the most favourable option. The pit limits were optimised using WHITTLE software and the layout of the mine as been finalized with all finer details. The pit will attain the ultimate depth of 160 m with ore to overburden ratio of 1:2.7. Ultimate pit slope has been designed for 47^0 up to a depth of 120 m and 44^0 below 120 m. The proposed mining at Banduhurang will be a conventional opencast mine using excavator-dumper combination. Careful selection of earth moving equipment has been done to maintain ore benches of 6m height and over burden/waste benches of 6 m/12 m height. A code of practice has been formulated for control of run-off-mine quality for this low-grade deposit with the introduction of bio-informatics. The pit will also undergo simultaneous back-filling with the over-burden (Fig. 2). The work on development of this deposit will start soon. The ore of Banduhurang mine will be processed in the new plant at Turamdih.



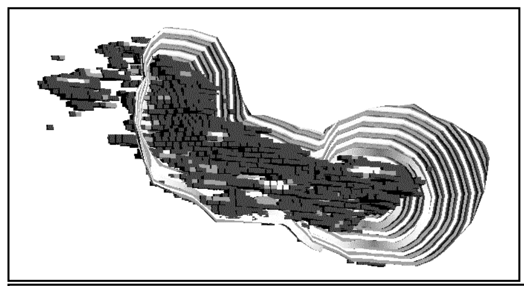
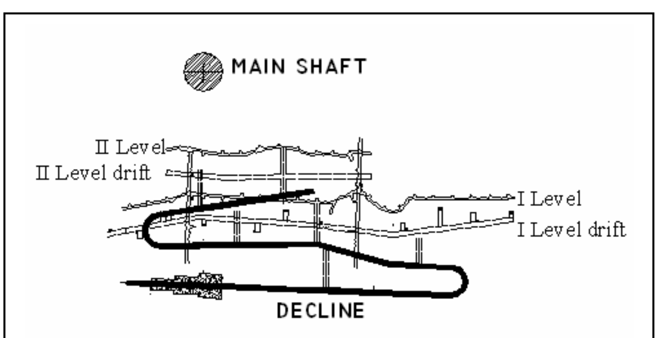
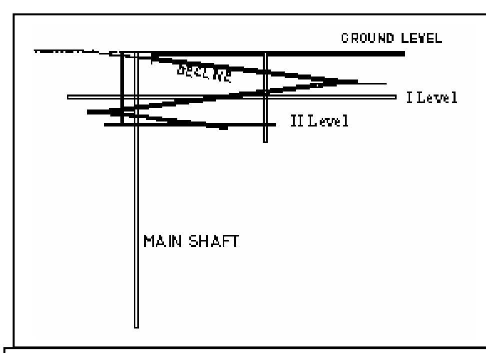


Fig. 2 **Ore body model of Banduhurang using SURPAC software** | **Pit optimization at Banduhurang using WHITTLE software**

Bagjata Mine: This deposit is about 30 km south-east of Jaduguda, where the ore body extends like a thin vein up to a depth of 600 m. This mine is being developed in the first stage up to 300 m. It will become operational soon with a 7^0 decline as the access into the mine. (Fig.3) The levels will be developed at 50 m interval. The method of stoping will be cut-and-fill with cross-cuts/ramps from decline as the entry to stopes. Moderate level of mechanisation with the deployment of single-boom drill jumbo, LHD, LPDT etc is proposed in this mine. A vertical shaft initially up to a depth of 375 m will be sunk to provide access of men and material to deeper levels. The ore of Bagjata will be processed in Jaduguda plant and the de-slimed mill tailings from Jaduguda will be sent to Bagjata for back-filling.



Plan showing Bagjata mine layout



Section showing Bagjata mine layout

Fig. 3

Mohuldih Mine: This deposit is located about 27 km west of Jaduguda, about 3 km west of proposed Banduhurang open cast mine. The ore body extends like a thin vein up to a depth of 320 m. This deposit will also be opened with a decline as the access and a vertical shaft up to a depth of 355 m will be used for men and material transport. The levels will be developed at 50 m interval. Trackless equipment will be employed in this mine. The principal method of stoping will be cut-and-fill. The ore of Mohuldih will be treated in the Turamdih plant.

3.3. New mines in the state of Andhra Pradesh

Lambapur-Peddagattu mine: The deposits in this region fall along the unconformity contacts of underlying granites and overlying quartzites. The flat orebody with varying thickness is spread over five distinct blocks and occurring within a depth of 15 m to 60 m. Considering the nature and depth of occurrence of ore lenses, one opencast mine and three underground mines have been planned in this region. The open pit mine will extend only up to a depth of 15 m with ore to overburden ratio of 1:4.2. The underground mines will be about 70 m deep accessed by declines. Room-and-pillar stoping method will be followed using low profile drilling machine, LHD and LPDT. Ore will be hoisted to the surface through central conveyor and transported by road to the plant.

3.4. New mines in the state of Meghalaya

Domiasiat mine: This deposit with large and good grade uranium reserve is hosted in a thick pile of sandstone within a depth of about 40m with underlying granite. A small rivulet flowing in the area divides the deposit into two separate mining blocks. Both the blocks – Killung and Rangam will be mined by open pit mining method up to a depth of 45 m with ore to overburden ratio of 1:6.7. The pit will be concurrently backfilled with mill tailings and overburden. (Fig. 4) Since the deposit falls in a very high rainfall area, special measures are planned for mine dewatering and the safe disposal of water to the aquatic environment.

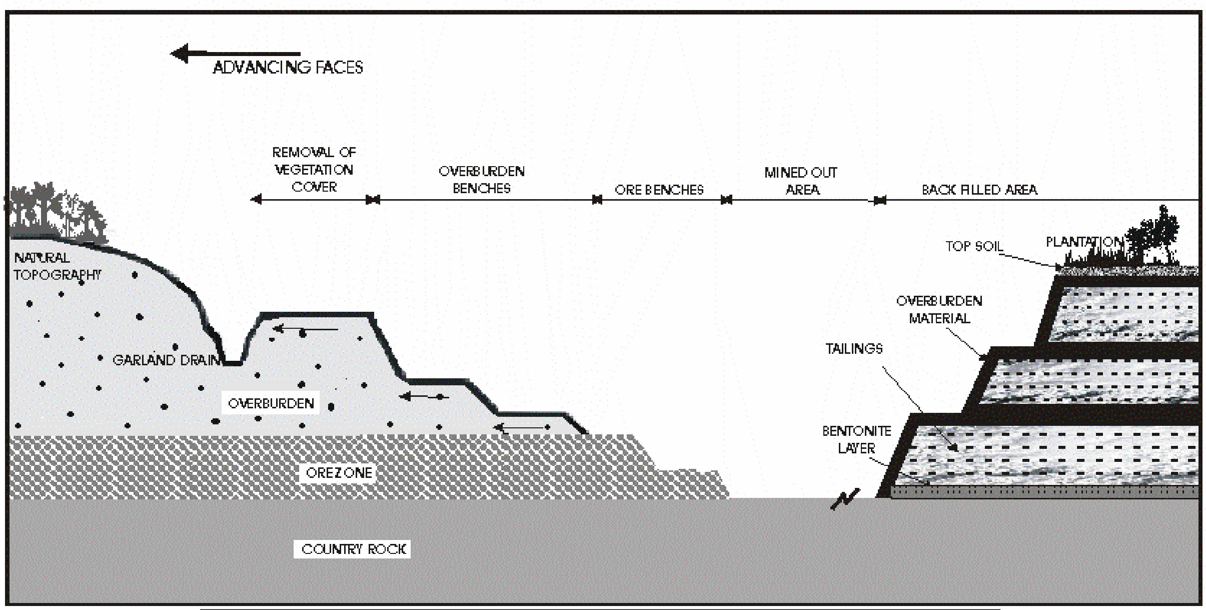


Fig. 4 **Schematic section of Domiasiat pit**

3.5 Prospective mines:

Pre mining activities are also set to begin in a few more deposits where the exploration is in an advanced stage and sufficient reserves have already been identified.

Tummalapalle uranium deposit: The large uranium reserve discovered in the Proterozoic Cuddapah basin in the state of Andhra Pradesh is hosted by carbonate rock formations. The strata bound ore body has been delineated up to a depth of 275 m extending like thin veins from surface. The orebody has fairly uniform dip and width. Underground exploratory mining work in this deposit has been completed confirming the configuration of ore body. The ore recovered from the exploratory mine is being used for various laboratory and pilot plant studies.
Rohili uranium deposit: This area in the state of Rajsthan is under advanced stage of detailed exploration. The steeply dipping ore body in the albitite host rock already identified up to a depth of 100 m holds the promise of a deep underground mine. Pre-project activities in this area will start soon.

4. Uranium ore processing in India

The uranium ore processing facility is an integral part of uranium mining industry in India. The upsurge in mining activity has therefore necessitated the expansion of existing plant and construction of a few more new ore processing plants to treat the ore generated from different mines.

4.1. Operating plant:

Jaduguda: The only operating plant of the country at Jaduguda in operation since 1968, is based on acid leaching technology. The process know-how has been indigenously developed and upgraded time-to-time keeping in pace with the global developments of uranium technology. Jaduguda plant has also been expanded twice, nearly doubling the original processing capacity to treat the ore of Bhatin and Narwapahar mines. In the coming years, ore of Bagjata mine will be fed to this plant.
The ore from different mines (upto 200 mm size) are crushed in two stages, primary jaw crusher and secondary cone crusher. The fine ore is wet ground in grinding mills in two stages for further size reduction. This ground ore in the form of slurry is thickened and leached in leaching pachucas for preferential solubilization of the uranium from solids under controlled pH and temperature conditions. The leached liquor is then filtered in which uranyl ions get absorbed in the resin. This is further eluted and treated with magnesia to get magnesium di-uranate or yellow cake. The magnesium di-uranate is then filtered in belt filter to remove soluble impurities, dried in a spray drier and finally packed in drums for onward dispatch for further processing. The plant has several automated process control mechanism and on-line monitoring system specially introduced during second phase of expansion. PLC based control system for ion exchange, DCS based on-line control system for control monitoring of pH in leaching pachucas, precipitation tanks and tailings plant, XRF based on-line analyzer for monitoring of uranium content in ion exchange, close circuit TV are some of the distinctive features in Jaduguda plant.

4.2. New plants

Turamdih: A new plant at Turamdih is being set-up to treat the ore planned to be produced from Turamdih and Banduhurang mines. The flowsheet of this plant is similar to that of Jaduguda. However, taking account of developments in hydrometallurgy / processing technology worldwide, some efficient equipment like apron feeders, particle size monitors, horizontal belt filter, pressure filter etc are being proposed in this plant. It has also been planned to encompass a very high degree of instrumentation minimizing human interference. PLC based control system shall be based on Man Machine Interface (MMI) with remote input-output and shall have facility to monitor process parameters, status of drives, control of relevant process variables and operate any equipment from plant graphics. Expansion of Turamdih plant to the higher level of processing capacity will be taken up with the progress of mine construction work at Mohuldih.

Seripalli: This plant has been planned in Andhra Pradesh to treat the ore of Lambapur-Peddagattu mines. The plant site is about 54 km away from Lambapur area as there are some environmentally sensitive places around the mine site. The design philosophy of this plant is similar to the processing practices proposed at Turamidh plant. Latest equipment and degree of instrumentation similar to the ones proposed at Turamdih, will also be adopted in Seripalli plant. However, the sizing of these equipment and provisions of flexibility to allow alternate processing technology to accommodate unexpected ore characteristics will be the vital aspects for Seripalli plant.

Domiasiat: This plant near the mine site at Domiasiat in Meghalya will be constructed with some modified process technology because of different ore characteristics. The host rock at Domiasiat is moderately friable sandstone, which will be crushed at the pit-head. Followed by conventional grinding in the plant, the thickened slurry of sandstone will undergo two stages of leaching – weak acid (WAL) and strong acid (SAL). Resulting filtrate will be clarified, concentrated in ion-exchange and precipitated along with magnesia as magnesium di-uranate or with hydrogen peroxide as uranium peroxide. The plant will also have PLC based central control system, on-line monitoring and XRF based on-line analysers etc.

4.3. Prospective plant:

Tummalapalle: As the host rock of Tummalapalle uranium deposit is siliceous-dolomitic-phosphatic limestone, alkali leaching technology is being proposed to treat this ore. The ore produced during exploratory mining are being utilised for several laboratory and pilot plant studies in order to finalise the process flow-sheet and other parameters. The uranium values are found to be present as very fine to ultra-fine disseminations predominantly in carbonate matrix. In such case, pressure leaching with oxygen as oxidant has been found to be more attractive than conventional leaching with chemical and gaseous oxidants. The proposed flowsheet involves reagent regeneration and includes very fewer number of process steps from grinding to sodium di-uranate precipitation. The alkali-leaching plant at Tummalapalle, after construction, will be the first of its kind in the country.

5. Uranium tailings management in India

The uranium ore in India are generally of low grade, which necessitates production and processing of large quantity of ore. This results in generation of large volume of solid waste and effluent. With greater public awareness of health hazards and stringent environmental guidelines, the management of these tailings (solid and liquid waste) has become a crucial part of emergent uranium mining sector.

5.1. Tailings disposal in mines:

The operating underground uranium mines of the country are carefully designed with suitable stoping method (cut-and-fill) to accommodate maximum tailings generated during the ore processing. As the mining work progresses, the void created are sequentially backfilled. In this process about 50% of the de-slimed neutralized tailings are safely disposed in underground. Similar underground disposal will also be followed in case of future underground mines in Singhbhum. The proposed opencast mine at Domiasiat is also being designed to sequentially store uranium tailings as backfill material after artificial lining at the pit bottom. (Fig 4)

5.2. Tailings management on surface:
The finer fraction of the neutralized tailings is likely to contain some radio-nuclides and chemical toxins. It is therefore, necessary to make a sound impoundment arrangement of storing these materials on surface separating them from the public domain. In India, two such design criteria are chosen to effectively manage the tailings.

5.3. Wet tailings disposal system:
The tailings pond at Jaduguda is designed for this system of impoundment. The tailings in the form of slurry is pumped through pipeline to the pond which has natural high hills on all three sides. The embankment constructed in the fourth side is designed to take the load of entire quantity of ore available in the deposits. The material used in construction of embankment consists of impervious clay towards the upstream, random fill material on the downstream side. The permanent drains have been constructed on all sides to prevent the flow of rain-water into the pond. The decantation wells are strategically placed at the inner periphery of the pond allowing the excess water only to flow out. This water is carried to the effluent treatment plant for necessary processing through a well-laid drainage system. The tailings pond proposed at Turamdih will also be designed on this philosophy with some improved floor lining to prevent any downward movement of effluent.

5.4. Thickened tailings disposal system:
In this method, the tailings which usually contain 20 – 30% solids is thickened in high rate / high density deep thickeners producing a highly viscous slurry (in the form of paste) which can be pumped and deposited in dry stacking area. The paste, because of its high yield stress value spreads all around at a gentle slope and forms a heap. As deposition continues, the heap grows in area and height. At the periphery small dykes are built to contain tailings within the disposal area. Once the desired height is attained, the deposition point is shifted to a nearby suitable location to form an adjacent heap. (Fig 5) This kind of deposition technique helps to utilise the stacking area volume to the fullest possible extent. Land requirement is also less in this system than wet disposal method as the tails are deposited above ground level. The tailings pond at Seripalli in Andhra Pradesh will be designed following this method and this will be first such TTD for uranium tailings in the country. Very stringent design criteria are being proposed for this tailings pond with various laboratory inputs.

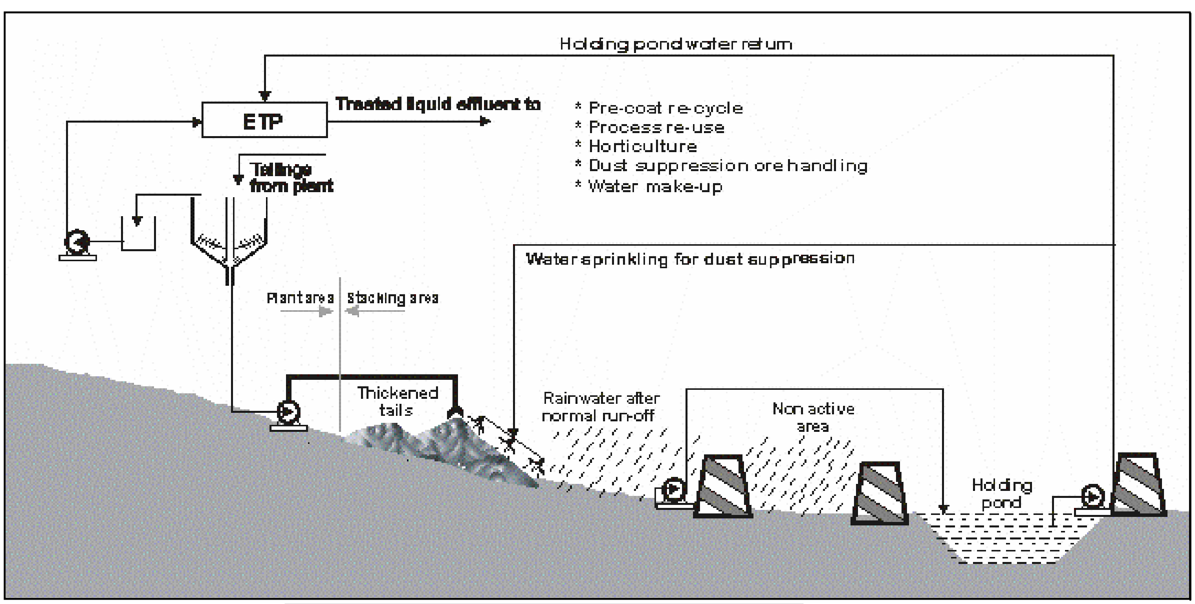


Fig. 5 **Thickened tailings disposal system**

6. Challenges and emerging technology

Uranium deposits in India are generally small, lean in tenor and complex in nature of mineralization. With the globalization of Indian economy, it has become imperative to develop these deposits in cost effective and eco-friendly manner assimilating the worldwide developments in science and technology. In order to meet the timely requirement of uranium, the construction activities need to be accelerated. Rising ore production from forthcoming new mines calls for some innovative approach of physical beneficiation of valuable uranium bearing minerals, which will reduce the volume of ore transportation and processing. The available flow-sheet also needs modification for improvement in recovery under different mineralogical conditions. The plants, with a shorter processing route, need to incorporate measures to maximize the re-use of water, high recovery of the product and minimum discharge of effluents. In the field of tailings management, long-term stability of tailings restricting the movement of contaminants, strengthening of embankment system, maximum re-use of effluents and reclamation of the existing ponds are some of the challenging areas for continuous research and improvement. However, rapid progress has been made in some of these areas by absorbing technology through fundamental transformations.

Use of integrated software (survey-geology-mine planning) has helped to quickly establish the configuration of ore body and assess the potential of the deposit. Standard modules of mine layout and method have been developed with minor variations to accommodate the site-specific geology. Similarly, standard modules and parameters for different processing activities are in place for implementation with site-specific modifications. This has considerably cut down time in planning, award of contracts for construction, drawing up specification for equipment and procurement. Uniformity in procedures for different studies like environmental assessment, feasibility, detailed project report etc has helped to reduce the pre-project period. Standardization of the layout and equipment has brought in significant cost advantage in the field of maintenance management and inventory control.

Mining in India has come a long way from conventional system to trackless mining, progressively emulating and absorbing global technology. In the existing mines, pneumatic equipment are systematically being phased out with the introduction of more energy efficient electro-hydraulic and diesel-hydraulic equipment. New mines are being planned with provision to automate all strenuous mining activities avoiding direct handling of radioactive ore at every stage of operation. Underground ventilation system, strata control measures etc are being simulated before field trial and implementation. The bulk ore assaying system with automatic grade estimation is undergoing continuous improvement. Country's dedicated mining research institutes have identified some of the thrust areas like cutting technology in place of conventional drilling & blasting, use of electronic detonators, environment friendly explosives etc for future development.

Keeping in view the worldwide technological progress in the field of ore processing, some major strides have been taken towards absorbing expertise and adapting cutting-edge technology through radical innovations. A great deal of efforts has already been made to implement precipitation of uranium peroxide ($UO_4.2H_2O$) using hydrogen peroxide in place of magnesium di-uranate. This will prevent co-precipitation of other metals, ensure higher purity in product and control many environment related problems. New plants with simpler and shorter processing route are being envisaged. Use of modern, energy saving and efficient equipment and concept of central control room are expected to be some of the distinctive features of new plants. Resolving the process know-how for alkaline leaching is now the emerging area for research and development, which can make the huge resource of Tummalapalle area exploitable. A dedicated state-of-art facility has been created at Jaduguda to pursue rigorous laboratory investigation / pilot plant studies in line with the above requirements. The research institutes of the country are also actively participating in time-specific projects for finding breakthrough in uranium mineral beneficiation, bio-leaching, bio- beneficiation etc.

Uranium tailings management has attracted enough interest of public and regulatory bodies in the country resulting in wide ranging research and development. The new tailings ponds are being envisaged with sound design features of embankment system and impermeable artificial liner to prevent any downward movement of effluent[4]. Various laboratory studies are being conducted to implement thickened tailings disposal (TTD) system at Seripalli. Remediation of existing tailings ponds at Jaduguda is being taken up on priority. Eco-restoration with suitable soil capping and vegetation are being addressed involving various premier research institutes. Efficacy of microbial leaching of tailings and microbial modifiers are also being looked into. Leachability characteristics of the tailings under different physico-chemical environment, studies pertaining to migration of contaminants into the adjoining environment, modification in tailings texture for minimizing dispersal of radon and its progeny are some of the critical areas for research in new tailings ponds of the country.

7. Future of uranium mining in India

During last five decades, with the increasing need of energy for the accelerated agricultural and industrial growth, the Atomic Energy Programme of our country has gained considerable momentum. 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. The Department of Atomic Energy accordingly, has very strategically designed the nuclear power programme of our country and an immediate goal has been set to produce 20,000 MWe of nuclear power by 2020 AD.

Self-reliance in basic raw materials is the dominant paradigm of nuclear power programme of India. Therefore, the growth of uranium industry has shown an extraordinary up-trend during last one decade. The industry is expected to expand further matching with the phenomenal growth of nuclear power generation in the coming years. Apart from supplying the raw material for nuclear fuel, the uranium mining industry in India has a great potential to contribute towards development of infrastructure, mining technology and generate employment opportunity in the nation.

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