XA0103130

MINING AND MILLING OF URANIUM ORE: INDIAN SCENARIO

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Abstract

The occurrence of uranium minerals in Singhbhum Thrust belt of Eastern India was known since 1937. In 1950, a team of geologists of the Atomic Minerals Division was assigned to closely examine this 160 km long belt. Since then, several occurrences of uranium have been found and a few of them have sufficient grade and tonnage for commercial exploitation. In 1967, the Government of India formed Uranium Corporation of India Ltd., under the administrative control of the Department of Atomic Energy, with the specific objective of mining and processing of uranium ore and produce uranium concentrates. At present the Corporation operates three underground uranium mines, one ore processing plant with expanded capacity, and two uranium recovery plants. Continuing investigations by the Atomic Mineral Division has discovered several new deposits and favourable areas. The most notable is the large Domiasiat deposit of the sandstone type found in the State of Meghalaya. This deposit is now being considered for commercial exploitation using the in-situ leaching technology.

1. INTRODUCTION

Soon after independence, the search to locate indigenous sources of uranium began as a sequel to the decision of Government of India to harness atomic energy for industrial purposes. It assumed greater importance with the rapid industrial development and limited availability of resources of fossil fuel and hydroelectricity in the country. Soon, it became imperative to locate uranium deposits in the country to meet the requirement indigenously. In the first decade of exploration, a number of areas showing anomalous concentration of uranium was identified all over the country specially in the states of Bihar, Rajasthan, Madhya Pradesh, Himachal Pradesh, Andhra Pradesh etc. (Fig. 1). Of all these locations, occurrences in the southern part of Bihar (Singhbhum Thrust Belt) were significant since they indicated the presence of uranium in mineable quantities.

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In 1967, Government of India formed Uranium Corporation of India Ltd. under the administrative control of Department of Atomic Energy with specific objective of mining and processing of uranium ore in the country to produce uranium concentrates. The Corporation started with one underground mine at Jaduguda in Singhbhum Thrust Belt of Bihar and a processing plant near the mine site. Later on, additional mining and milling facilities were created to meet the growing demand. The technology of uranium extraction is amply demonstrated by the working of the mill and mine at Jaduguda which has already completed three decades of uninterrupted production. As on today the country boasts with three underground uranium mines, one uranium processing plant with expanded capacity and two uranium recovery plants operating under the Corporation.

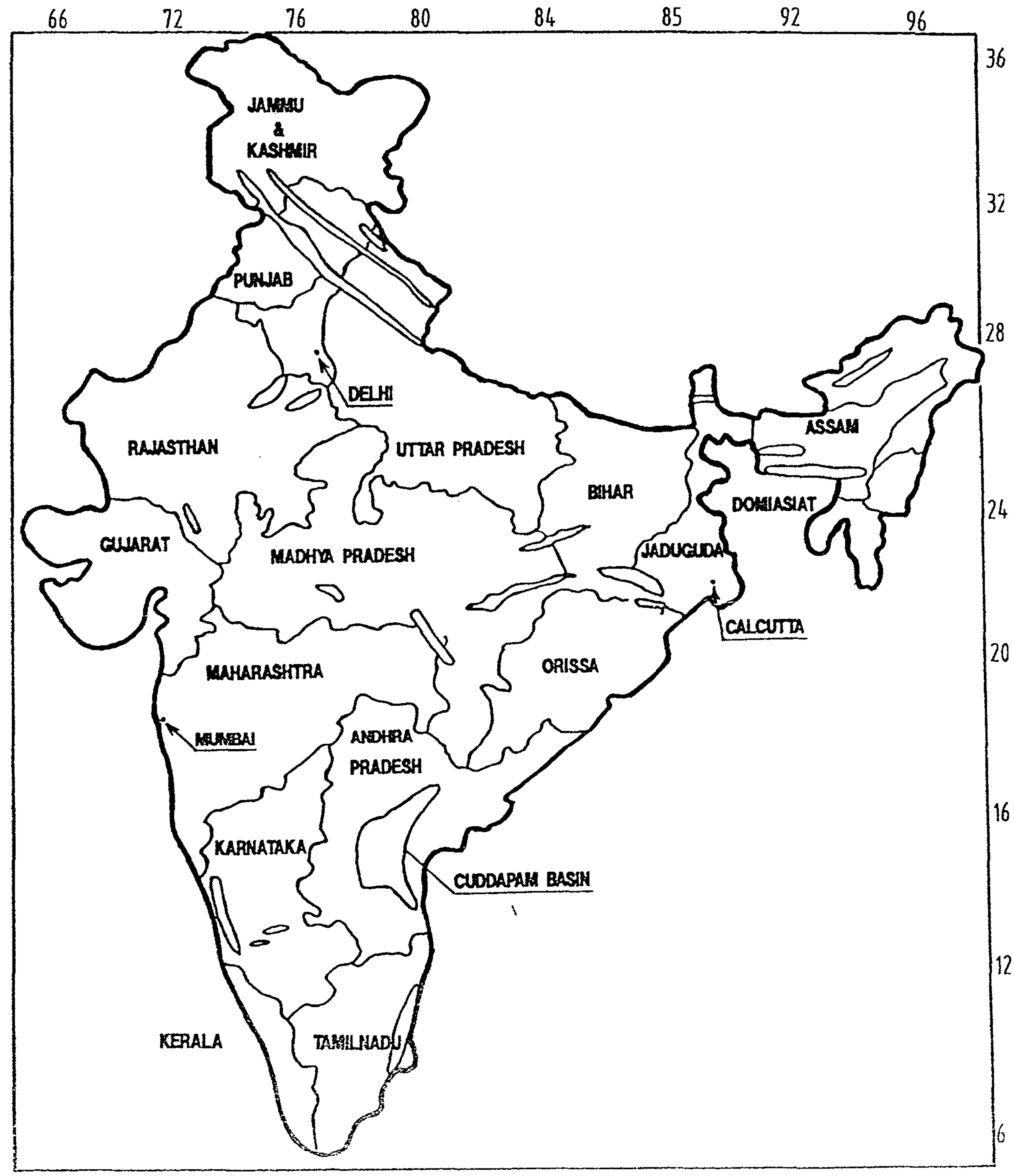

FIG. 1. Belts of uranium potential in India.

2. UNDERGROUND MINES

2.1. Jaduguda mine

Geologically, the deposit belongs to a zone of thrusting and shearing. The thrust belt is constituted by Archean metasediments. Older rocks (Chaibasa stage) have been thrust over the younger rocks (Dhanjori stage). The thrust contact is severely sheared and brecciated. Uranium occurs in this brecciated zone in a very finely disseminated form. The mineralisation

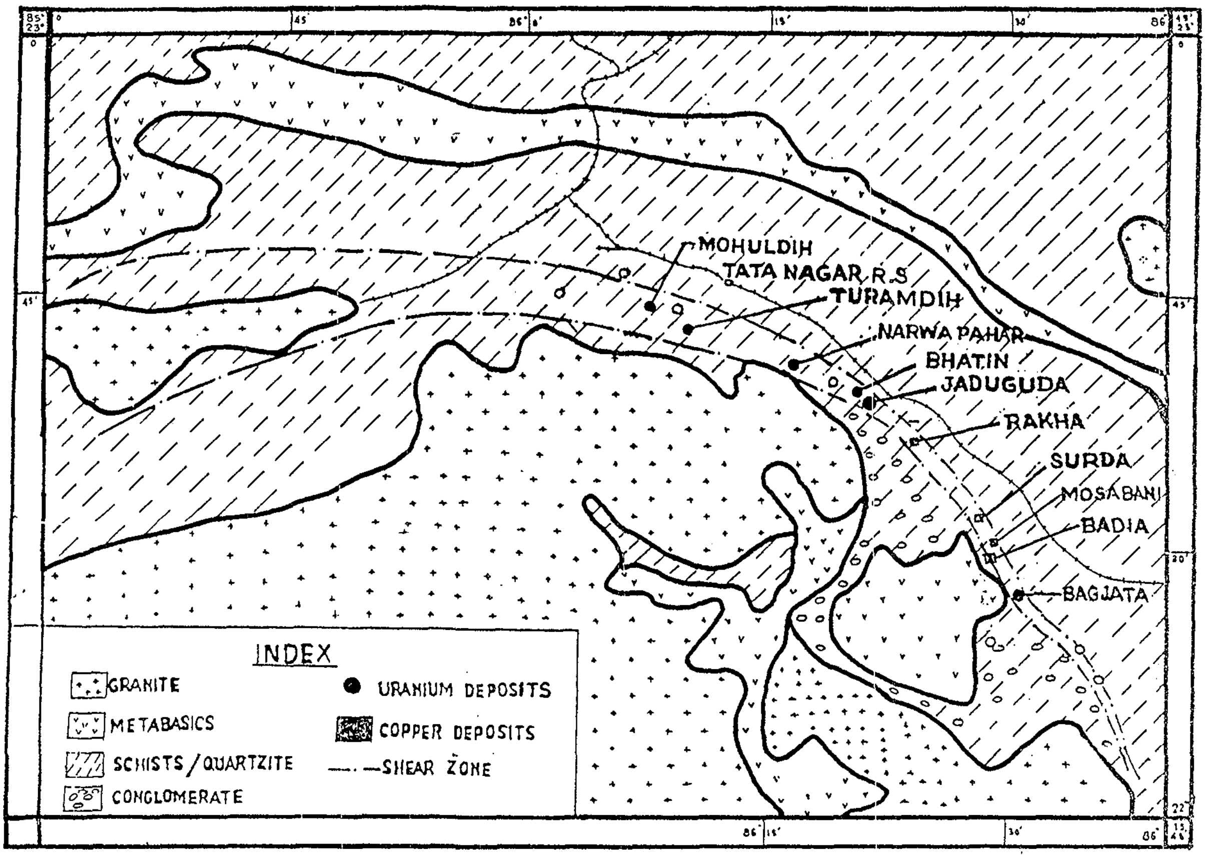

FIG. 2. Geological map of Singhbhum shear zone, showing uranium & copper deposits.

is structurally controlled and is confined to shears lying parallel to sub-parallel to the schistosity. The principal mineral of uranium is uraninite (Figs. 2 and 3).

The deposit has two lodes. The southern lode, known as the Foot-wall lode extends over a strike length of about 800 m from south-east to north-west. The northern lode, known as Hang-wall lode has a strike length of about 200 m and is noticeable only in the eastern sector. The ore shoot in the western sector of foot-wall lode is not only rich in uranium but also contains copper, nickel and molybdenum. The width of the orebody varies from 2 m to about 25 m with a moderate dip of about 40°.

Jaduguda mine is the first underground uranium mine in the country which is in continuous commercial operation for the last three decades. The deposit was discovered in April 1951. Detailed exploration by diamond drilling and initial exploratory mine development work was started soon followed by mine development work through adits and winzes. By the year 1964, mine had reached a depth of 100 metres below surface. Then a shaft was sunk up to a depth of 315 m along with the ore pass system, underground loading and crushing stations were made ready to produce 1000 tonnes of ore per day. The mine was deepened in second stage by deepening the shaft from 315 m to 640 m along with the production from the top levels. A novel method was used for the construction of this shaft. The main ore pass was sunk first and the shaft was raised from bottom to top. Instances of this method is very few and far in the world. The second stage shaft sinking was completed in 1977 and mining was commenced from deeper levels. The main shaft is completely lined with 5 m finished diametre and

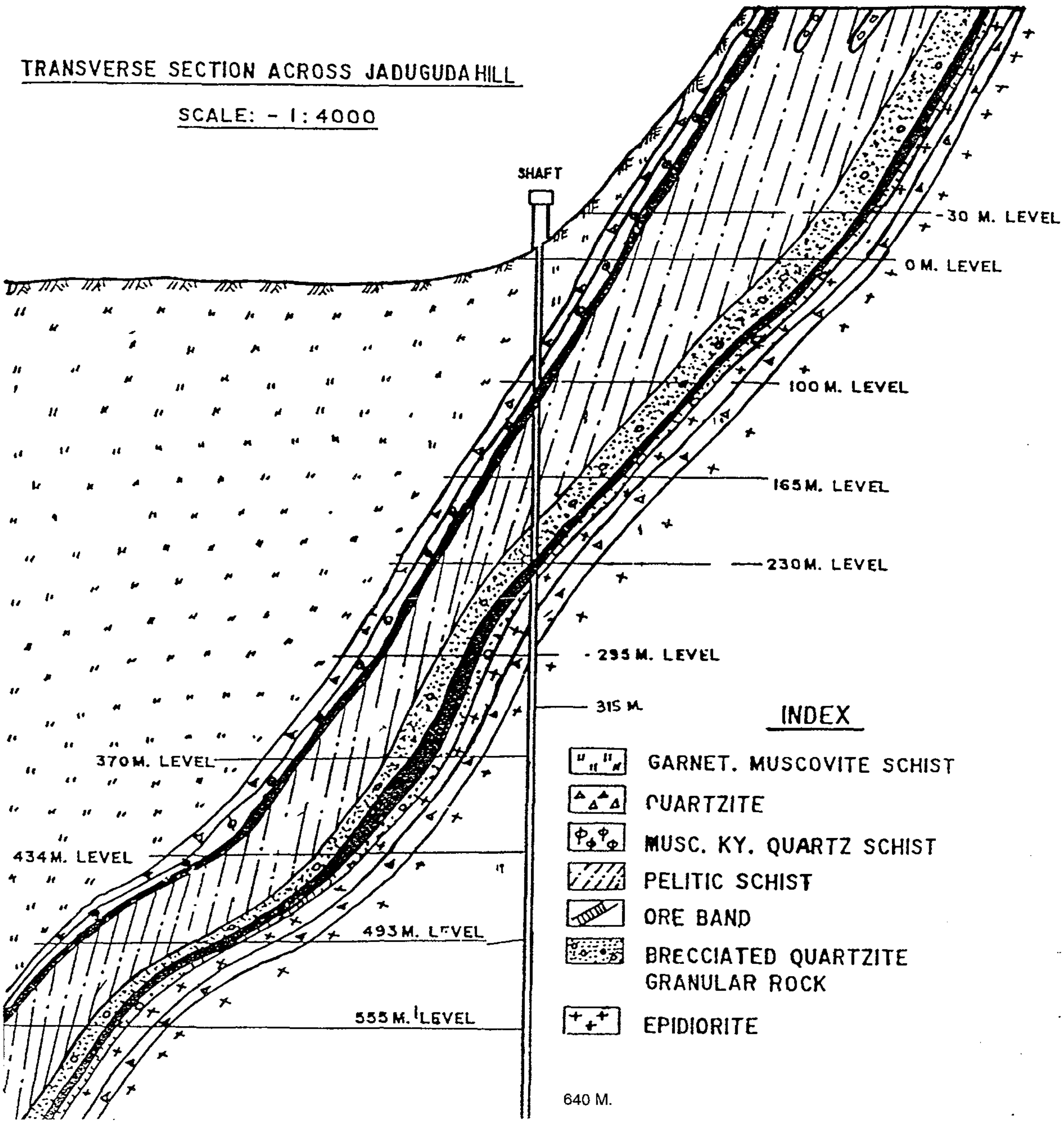

FIG. 3. Transverse section across Jaduguda hill.

equipped with two multi-rope friction winders, one for the cage and the other for the skip. The cage has two decks which is used for lowering men, material and hoisting of waste rock. The skip of 5 tonne capacity is used exclusively for hoisting of ore from 605 metre level (loading station). The winders are installed on an R.C.C. tower of 7.50 metres diametre at a height of 45 metres above the ground.

In the earlier stages, to boost production and to build up ore stocks shrinkage stopping was followed in the mine. Later on open timbered method of stopping was adopted. Presently the principal stopping method is the horizontal cut-and fill using deslimed mill tailings as the fill material. The levels are generally opened at 65 metres vertical interval and are connected to the ore drives. The ore produced from different levels in the mine are transferred to an ore-pass located near the main shaft. All the ore transferred from different levels are sized in an underground jaw crusher at 580 metre level. The crushed ore is stored in the ore pocket below the crushing station. The ore is finally hoisted to surface from 605 metre level loading station.

Shrinkage stopping adopted in upper levels during early stage of mining provided the opportunity for application of solution mining. Due to flat dip of the orebody, some ore was adhering to the footwall even after drawl from the chutes. Barren solution from the mill was sprinkled into the stops and re-circulated till values were built up. This water rich in uranium was then pumped to mill for uranium extraction. Considerable amount of uranium has been extracted by this novel method.

Jaduguda is a well designed mine with a nice functional layout not only for production but also for transportation and drainage system. It is the first underground metal mine in the country to be commissioned after independence. It is the first mine in the country to introduce a number of new techniques like using slip form method for shaft lining and construction of shaft headframe, use of trackless pneumatic loaders like LHD & CAVO, Alimak Raise climber for development of long raises, stope wagon for mechanized drifting, underground crusher etc. Presently, the mine is adopting better mechanisation for deeper levels by developing decline and ramp as an approach to stops and using electro-hydraulically operated twin-boom drill-jumbo, low-profile-dump-trucks etc. This upgrading of technology is expected to result in better stope productivity.

During last thirty years of mining, Jaduguda mine has gone to a depth of 555 m. Entire ore up to a depth of 434m has been exhausted. Present mining operations are confined to 495 m level and 555 m level. As the reserve depletes, continuous search and underground exploration has led to prove that the uranium bearing lodes of Jaduguda extends to a vertical depth of 750m and below. This has led to take a major decision to deepen the mine to 900 m by sinking an underground vertical shaft. This is referred as third stage of mine deepening (Fig. 4). With the find of the orebody and deepening of the mine, the life of the deposit is expected to increase by 20 years. The sinking work commenced in June 1992 and was completed in 1997. Shaft lining work is in full swing and will be ready for 3 commissioning soon. Orebody shows encouraging indications of continuity below 900m. In such an event, mine will be deepened further as fourth stage of operation after studying the feasibility.

2.2. Bhatin mine

It is a small, low grade deposit located at about 3 km west of Jaduguda in Singhbhum Thrust of Bihar state (Fig. 2). Uranium bearing outcrop on the top of the hill were traced at the initial stage of exploration. Subsequently, it was prospected by shallow and deep bore holes. Deep boreholes have indicated that the mineable orebody persists to a depth of 600 m.

The deposit is the western extension of Jaduguda orebody that has been displaced to the north due to a regional strike-slip fault (Tirukocha fault) in the post mineralisation stage. The geological settings, host rock and mineral characteristics are similar to Jaduguda deposit. The strike length of the deposit is about 400 metres having a dip angle of 35 to 45 degrees. The ore lenses occur in lenticular pattern. The average width of the ore-body varies between 2.50 m to 7 m. The deposit has a very high concentration of molybdenum which has been emplaced later to uranium minerilisation along some localised shear planes.

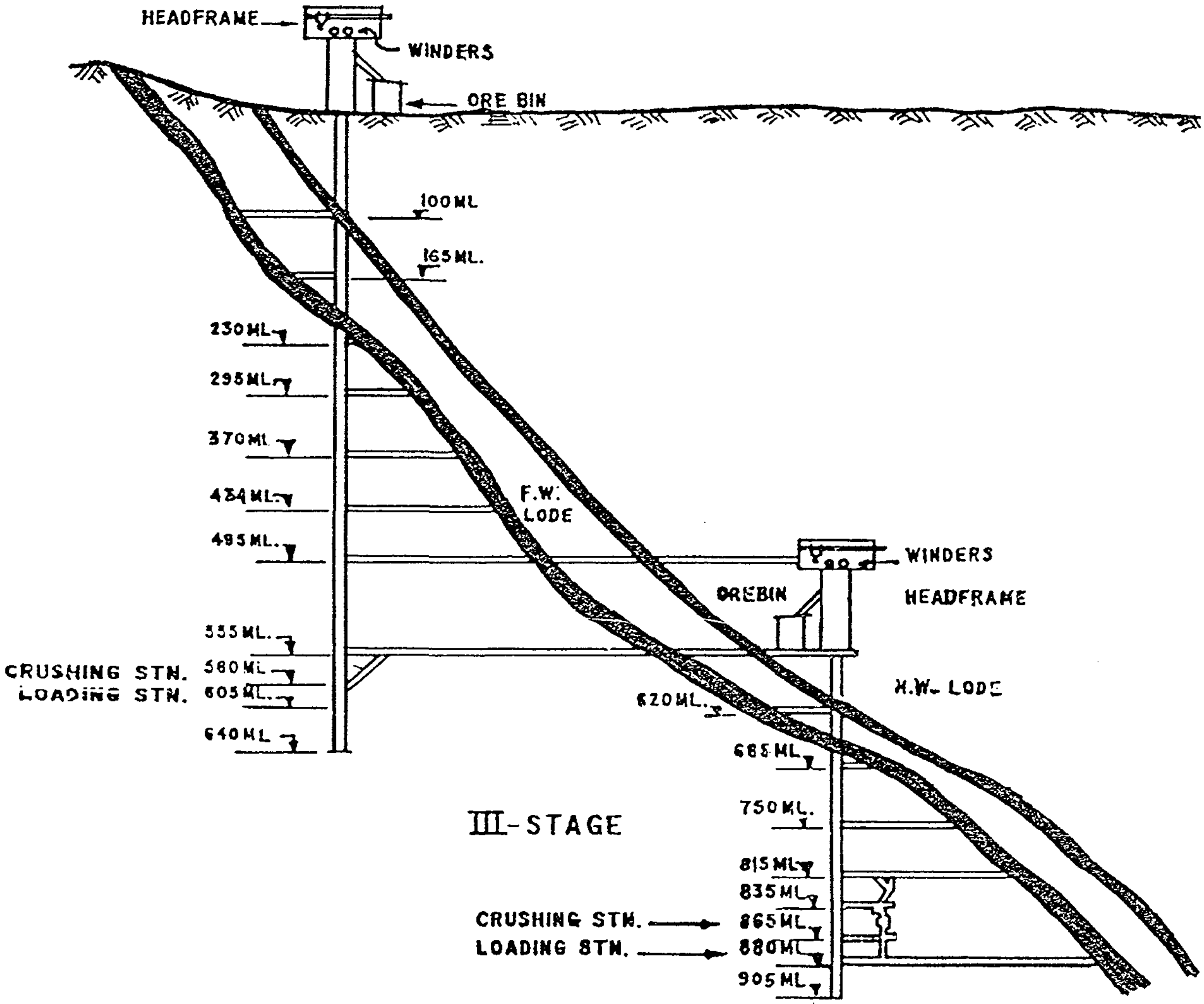

FIG. 4. III - Stage shaft sinking.

The proximity of this deposit to Jaduguda and the fact that its geological settings and ore mineral assemblages are similar to that of Jaduguda, made its commercial exploitation an attractive proposition. The mine construction work started in April 1983, and was commissioned in October 1986. The mine designing and construction work was carried out indigenously. The entry to the mine is through an adit driven at the ground elevation (second level). Two principal underground winzes have been sunk from this level to sixth level, a vertical depth of 135 metres below surface. The winzes are equipped with double drum electric hoists used for lowering of persons and hoisting of ore from the lower levels. A level has also been opened 25 m above the second level to win the ore above ground elevation. The capacity of the mine is to produce 250 tonnes of ore per day.

The principal stopping method followed is the horizontal cut-and-fill using deslimed mill tailings as backfill material. Stopping and transportation layout of the mine are similar to Jaduguda. Ore produced from Bhatin mine is transported to the processing plant at Jaduguda by dumpers and backfill material is obtained from there.

As the reserve in the upper level depletes, the mine is now being deepened to create additional production levels below 185 m. The existing winzes are being deepened up to a depth of 250 m and will be ready for use soon. Depending on the nature of mineralisation, subsequent deepening of the mine will be carried out either by sinking vertical shaft or by developing underground decline.

2.3. Narwapahar mine

It is located at about 12 kms north-west of Jaduguda (Fig. 2). Exploration of this deposit was carried out at a later stage. The deposit lies in the metasediments of Singhbhum Thrust Belt. The effect of regional thrusting in this zone appears very intense.

The metasedimentary sequence in Narwapahar deposit consists of a series of schistose rocks of varying composition. The uranium mineralisation is confined to the schistose units and is concentrated principally at a lithological boundary. The principal uranium mineral is uraninite which is finely disseminated throughout the host rock. There are a number of uranium bearing beds occurring as tabular lenticular horizons conformable with dip and strike of the schistosity. But six prominent bands are found mineable. At their maximum extend, the orebodies have a strike length of about 2 km and is known to persist to a depth of 600 m. The width of the orebody varies from 2 m to 7 m. Variations in thickness of each orebody exists along the strike as well as the dip. The dip of the orebody is about 30°.

The mining method adopted at Narwapahar mine is the most modern in the country Even very few mines in the world have perfected on this methodology. The entry to the mine is through a decline in the footwall of the orebody. Low gradient ramps are developed as entry to the stop. This has helped in using large trackless mining equipment like twin boom drill jumbo, low-profile-dump-truck, service truck, passenger carrier, low-profile road grader, scissor lift etc. Provision of ramp in stope has helped in moving machinaries from one level to another. The method has brought in early commissioning of the mine for production, low cost and high productivity. Such technology has allowed interchanges between different stoping methods that becomes necessary due to the wide variations in thickness and differing configurations of the orebody.

Presently, the decline has been developed to a depth of 140 m and four levels at intervals of 35 m below surface are under production stage. Three different stoping methods are adopted in Narwapahar Mine. For orebody width up to 2.5 m, inclined room-and-pillar method is followed. Step mining method is followed for thickness ranging between 2.5 m to 7 m, and for thickness above 7 m Post Pillar method is followed. The voids in the stopes are filled with deslimed mill tailings. The long term as well as short term stability of the surface is ensured after analysing all the above methods of extraction technique by means of numerical modelling using BEFE software. Any modifications to the design layout of the mine is first tested for stability point of view before adopting them in practice.

A vertical lined shaft of 5 m finished diameter has already been sunk up to a depth of 355 m which will serve as an entry to deeper levels. Shaft equipping work is in progress. Narwapahar mine shaft will have two ground mounted friction winders - one for the cage winder and the other for skip. The general arrangement in this shaft will be similar to the main shaft of Jaduguda mine like ore-pass system, underground crusher and loading station etc. After the commissioning of the main shaft, it will be connected to the mine and ore from lower levels of the mine will be hoisted to surface through skip.

Narwapahar mine is designed to produce 1000 tonnes ore per day. All the ore from Narwapahar mine is transported to Jaduguda mill for processing and backfill material is taken from mill to the mine site.

3. PROCESSING PLANT

Processing of ore is an integral part of the mining. The ore extracted from Jaduguda mine is being processed at Jaduguda mill which was made ready a little after the commissioning of the mine.

The ore from Jaduguda is transported by conveyor belt to crushing section in two stages. This is followed by two stage wet grinding with primary rod mill and secondary pebble mill. The ground ore in the form slurry is then pumped to by-product recovery plant for the recovery of copper, nickel and molybdenum sulphide as concentrates using flotation technique. The slurry after flotation is thickened, filtered, repulped and pumped for leaching in pachucas which are essentially air agitated tanks. During the process of leaching, tetravalent form of uranium is oxidised to hexavalent form which is soluble in acidic medium. For this sulphuric acid and pyrolusite are added to maintain pH. Temperature is maintained between 36°C to 38°C. The pachucas are kept in line. The slurry overflows from one pachuca to another and after twelve hours of retaining when the slurry comes out of the last pachucas, around 95% of uranium get leached out. The leached slurry is filtered in two stages employing string discharge vacuum drum filters. Primary filtrate is clarified on filter aid coated pre-coat filters and sent to purification and concentration. Secondary filtrate is sent to disc filter for repulping ore cake.

The liquor at this stage contains 0.4 - 0.6 gm/l of U_30_8 ferrous and ferric sulphates, dissolved manganese, sulphate ions and other impurities. This is concentrated and purified by ion exchange process. Two columns-system with strong base ion exchange resin is used. The liquor is passed through both the columns. Once U_30_8 from second column is found 0.005 gm/l the first column is cut off and eluated with normal acidified salt solution. The strong eluate so produced contains around 4-5 gm/l U_30_8 ferric ions etc. This liquor is neutralised with lime to pH 3.9 whereby ferric ions gets precipitated. This is thickened and filtered. As along with iron some of the complexes of uranium also gets precipitated, it is sent back to leaching to recover the precipitated uranium. The clear liquor from thickener is neutralised further to pH 7 by magnesia whereby uranium gets precipitated as magnesium-di-uranate or yellow cake. This is thickened, filtered, dried and packed in drums. U_30_8 content in yellow cake is about 74%. The yellow cake is sent to Nuclear Fuel Complex for further processing for conversion into nuclear fuel grade.

The mill at Jaduguda is under continuous operation since its inception in 1968. With the commissioning of Bhatin mine in 1986, the capacity of the mill was expanded in 1987 to 1370 tonnes per day. Further expansion of the mill was undertaken in 1995 to treat the additional ore produced from Narwapahar mine. The fully automated expanded mill has been commissioned recently treating 2090 tonnes of ore per day. The new plant is now equipped with some of the state-of-the-art process control system like Distributed Control System,. PLC's and on-line XRF based uranium analyser to monitor and bring out efficiency in recovery.

4. URANIUM RECOVERY PLANTS

Adjacent to uranium mines in Singhbhum Thrust Belt of Bihar, a few large underground copper mines are under operation. These copper ore contain small amount of uranium minerals which can be recovered as by-products and they have become the auxiliary source of uranium in the country. Two such recovery plants at Rakha and Moosabani are set up near the copper concentrators in the region. After the extraction of copper, tailings are sent to these plants for recovery of uranium. Though the uranium content is very negligible in these tailings, the enormous volume available makes the uranium recovery process very attractive. The copper tailings are subjected to gravity separation using Wilfley tables. High specific gravity particles get concentrated at the bottom of the flowing film. The grade of uranium in mineral concentrates during the process goes up by 4 to 7 times. These uranium mineral concentrates are transported to Jaduguda mill by road for further processing. Efforts in this regard has not only generated an appreciable amount of uranium for the country, but has also gone a long way in minimising the radiation and pollution hazards from the waste streams of copper concentrators.

5. NEW DEPOSITS

Investigations and exploration carried out by Atomic Minerals Division through out the country has established many new mineable reserves and potential areas of which mention may be made of Turamdih, Mahuldih, Bagjata of Singhbhum Thrust Belt in Bihar, Bodal-Bhandaritola in the state of Madhya Pradesh, Lambapur in Andhra Pradesh, Shiwalik formations in the foot hills of the Himalayas etc. However, the greatest and the most noteworthy discovery of this decade is the large sandstone type deposit in the upper Cretaceous-Tertiary sedimentary basin at Domiasiat in the state of Meghalaya. With the increasing demand of uranium to meet the fuel requirements for country's nuclear power programme, the deposit is now being considered for commercial exploitation.

5.1. Domiasiat uranium project

The deposit is located in the southern slopes of Meghalaya plateau in West Khasi Hills of Meghalaya. A detail study of geology and genetic evolution of the Domiasiat uranium deposit has also opened up large areas for discovering similar deposits elsewhere in Meghalaya plateau.

Domiasiat deposit is the first of its kind in the country to be found in the sedimentary basin. The basement of this basin is intruded by Pre-Cambrian rocks. Uranium mineralisation is associated with grey, fine to medium grained sediments. These sediments directly overlie the basement granites (Fig. 5). Mineralised bands are confined within 45 m depth from the surface. They are fairly flat with general dip of 5 to 10 degrees. Thickness ranges from 1.5 m to 29.6 m averaging 3.57 m. A few more deposits with similar geological features have also been discovered in Domiasiat plateau and are in advanced stage of exploration.

Analysis of geology of Domiasiat uranium deposit with respect to its formation history and technical properties show its amenability to in-situ leaching technology.

The technique of in-situ leaching, is a relatively unknown method in India, though it is largely practised and successfully implemented in many countries of the world. Extraction in this method is accomplished through the dissolution of natural in-place uranium in underground and recovery of the leached solution from underground for further processing. Suitable solvent liquid is sent into the ore body through the injection wells, the liquid is allowed to pass through the orebody for desired period so as to dissolve the metal and finally the pregnant liquor is recovered through production wells. Monitor wells are also installed to regulate the excursion of liquid beyond the mining environment.

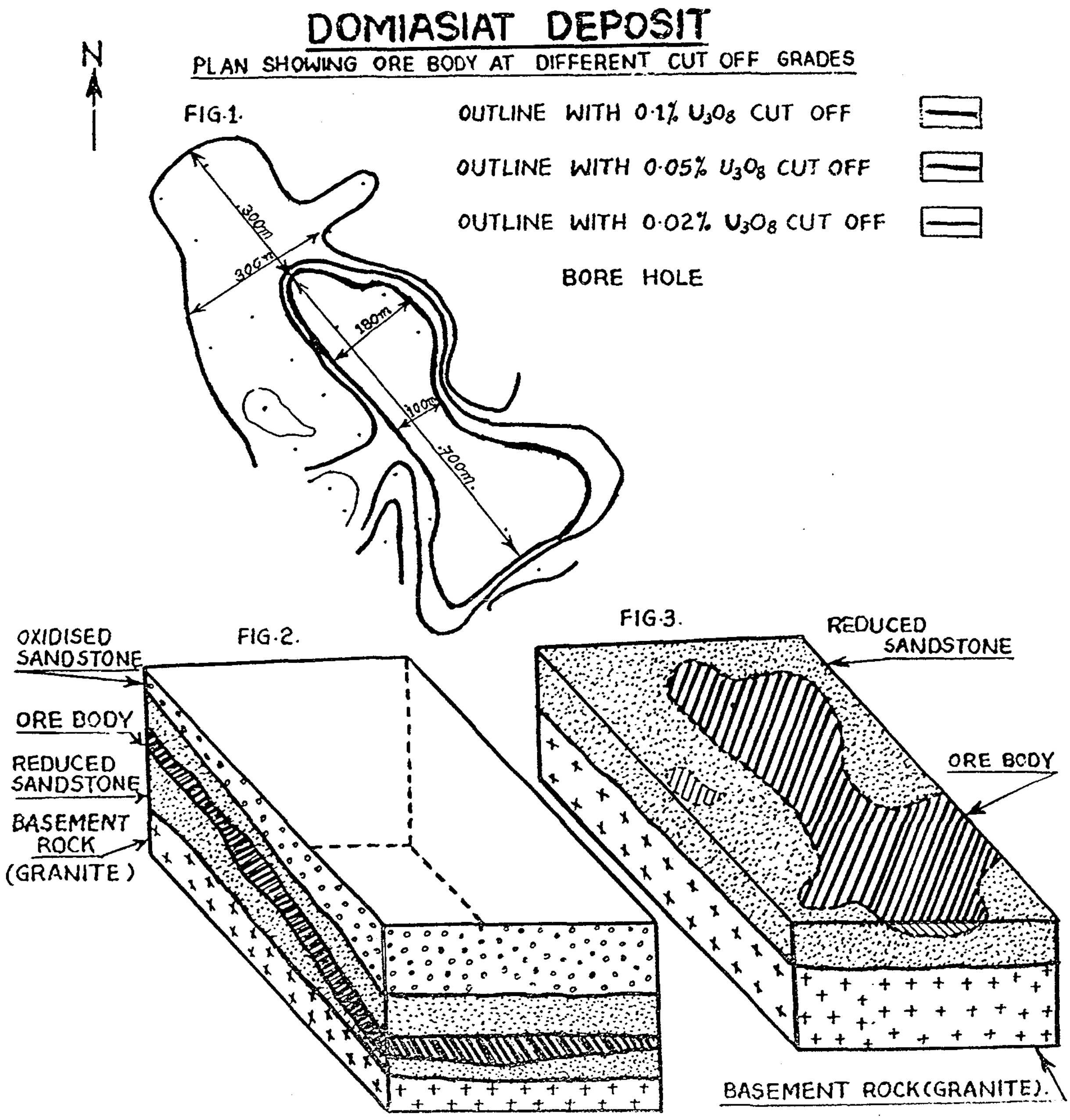

FIG. 5. Domiasiat deposit.

There are many advantages of adopting In-situ Leaching technique in Domiasiat over other conventional methods like open-pit or underground mining.

(A) Unlike in conventional mining and processing, following operations will not be required.

- (a) overburden removal
- (b) drilling/blasting in overburden and ore
- (c) surface transport of broken rock
- (d) maintenance of roads required for transportation
- (e) crushing & grinding of ore
- (f) tailings disposal system.

(B) Better economic indices of the deposit because of
- (a) Lower capital cost
- (b) Less manpower
- (c) FEgh productivity
- (d) Quicker return on investment.

(C) Environmental damage to the mine site will be considerably reduced because
- (a) Surface disturbance/infrastructure is minimised.
- (b) Large quantities of rock/tailings are not to be disposed of
- (c) Radium which is a major source of radiation will be left in the host rock.

(D) Less requirement of land will make land acquisition and subsequent re-cultivation possible.

(E) Unfavourable geology like incompetent host rock, poor ground conditions, water in-flows etc. will act to the benefit of the method.

(F) Continuous operation throughout the year will be possible inspire of unfavourable climatic conditions.

(G) Early production from the deposit can be achieved.

(H) Nearby, small, poor/low-grade deposits can be opened with minimum investment on infrastructure.

Presently, some more technical information specially related to the geo-hydrological properties of the deposit are being generated. Field tests with wide complex investigations for choosing the optimal ISL technology for the project are being planned. These tests will include well drilling, recovery and restoration of aquifer which may offer a model project for its application in other deposits also.

6. CONCLUSION

India is one of the few countries in the world where the entire gamut of nuclear fuel cycle is well developed entirely by an indigenous effort. There is a steady growth in installed capacity of the nuclear power plants during fast few years and this has necessitated a comparative growth of uranium mining and milling capacities. The known reserves are sufficient for the planned growth but there is a need for stepping up of exploration and identifying additional resources. Unfortunately, the country is not blessed with any rich grade uranium deposit. Deposits which would have been easier to discover have almost all been found out so that the future exploration demands greater ingenuity and skill based on sophisticated technique and advanced research out-put. The technology of uranium mining and processing though has been amply demonstrated, still the efforts are on to bring new deposits into production as early as possible, to reduce the cost of production, to improve upon the recoveries in processing and improving the recovery from copper tailings etc. The thrust areas are now well defined and prioritised to meet the requirement with alacrity and ability.

Radiation exposure during mining & milling operations

Average Annual Dose to Mine workers during 1997.

Jaduguda mine	:	7.19 mSv	Against Annual limit of 20 mSv
Bhatin mine	:	7.48 mSv	
Narwapahar mine	:	6.40 mSv	

Average annual dose to mill workers during 1997 was 2.88 mSv against the limit of 20 mSv.

Average radiation & radioactivity levels

Location	Av. Gama radiation □Gy L^{-1}	Av. Rn. concentration Bq m^{-3}, EER	Long lived radioactive dust Bq.m^{-3}	MDV Dust Av. Bq.m^{-3}
Jaduguda mines	2.65	460	0.04	---
Bhatin mine	2.80	440	0.01	---
Narwapahar mine	1.80	410	0.02	---
Jaduguda mill	2.84	--	0.03	1.29
Derived limit	8.0	1000	0.06	4.50

Public Exposure: 0.43 mSv/y above local natural Background (limit: 1 mSv/y)

Average Gamma Radiation Dose in Public Domain: 1.35 mSv/y

Local Natural background: 0.92 mSv/y

0.43 mSv/y