

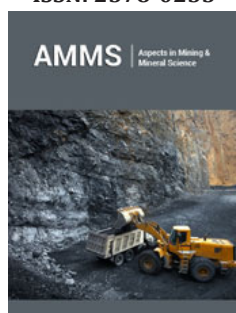
Aspects in Mining & Mineral Science for Nuclear Fuel Production in India

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Abstract

India's growing energy demands have intensified the strategic significance of uranium as a fuel for its expanding nuclear power program. This paper explores the key aspects of mining and mineral science related to nuclear fuel production in India, including geological occurrence, exploration techniques, mining methodologies, and beneficiation processes. The focus is on sandstone-type and unconformity-related nuclear fuel deposits predominantly found in Jharkhand, Andhra Pradesh, and Meghalaya. Advancements in radiometric surveying, drilling technologies, and leaching are also analysed. The role of the Uranium Corporation of India Ltd. (UCIL) in driving indigenous uranium supply and the environmental challenges associated with mineral ore mining are discussed. The paper highlights the need for sustainable practices, regulatory reforms, and technological innovation to enhance nuclear fuel recovery while minimizing ecological impact. These insights support policy frameworks and research directions for efficient, eco-friendly nuclear fuel production in India.

Keywords: Nuclear fuel mining; India; Nuclear energy; *In-situ* leaching; Mineral exploration; Sustainable extraction

Geological and Exploration Techniques

The initial stage involves remote sensing and airborne radiometric surveys to identify uranium anomalies. This is followed by ground-based geophysical methods, including resistivity and magnetic surveys, to delineate mineralized zones. Core drilling and trench sampling are employed for geological modelling and grade estimation. Stratiform, vein-type, and sandstone-hosted deposits in regions such as Jaduguda (Jharkhand), Tummalapalle (Andhra Pradesh), and Domiasiat (Meghalaya) are targeted due to their favourable lithological and structural controls [1].

Mining Methods

Uranium mining in India is executed through a combination of mining methods tailored to the geological and environmental conditions of each deposit. Conventional underground mining, particularly the horizontal cut-and-fill technique, is practiced at the Jaduguda mine, allowing efficient ore extraction in narrow, steeply dipping veins. Open-pit mining, on the other hand, is used in the Banduhurang deposit where ore bodies are closer to the surface, making it economically viable and operationally simpler. At more recent sites such as Nawapahar and Tummalapalle, advanced mining techniques have been introduced, emphasizing eco-friendly practices with minimal surface disruption, thus reducing environmental impact [2]. Across all mining sites, strict adherence to safety protocols is maintained, particularly regarding radiological exposure and ventilation, as mandated by the Directorate General of Mines Safety (DGMS) and Atomic Energy Regulatory Board (AERB), ensuring both worker safety and environmental compliance.

Ore Processing and Beneficiation

The processing of mineral ore in India involves a series of well-established metallurgical operations aimed at efficient recovery of uranium oxide (U_3O_8), commonly known as yellowcake [3]. The process begins with comminution, where the ore is subjected to crushing and grinding to reduce particle size and increase surface area for subsequent chemical reactions. Following this, leaching is employed to dissolve the nuclear fuel i.e. alkaline leaching is utilized at Tummalapalle due to the ore's high carbonate content, while acid leaching is preferred at Jaduguda for its suitability to the local mineralogy [4]. The resulting solution undergoes solid-liquid separation, and uranium is extracted through ion exchange and precipitation techniques. Critical to the process is reagent optimization and pH control, which enhance recovery efficiency while minimizing chemical consumption [5]. Moreover, tailings management is rigorously implemented to ensure the safe disposal of residues and protect surrounding ecosystems from radiological and chemical hazards. Figure 1 represents details of Nuclear Fuel mining and processing in India.

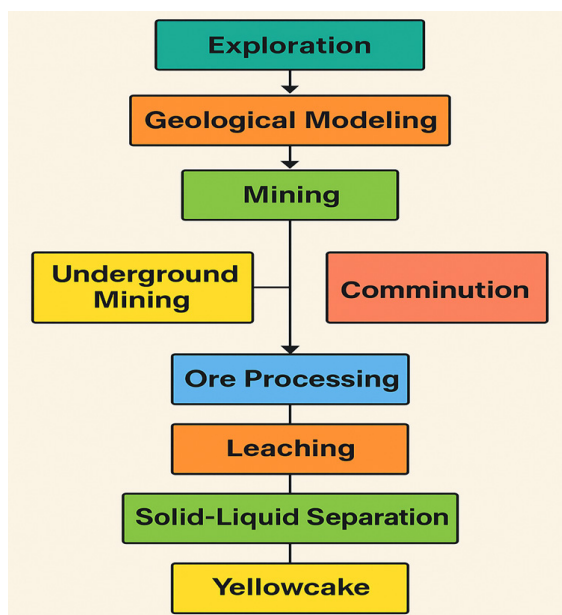


Figure 1: Nuclear fuel mining and processing in India.

Environmental Monitoring

Environmental baseline studies include soil, water, and air quality monitoring using ICP-MS and gamma spectrometry [6]. Tailings ponds are designed for long-term containment. Hydrogeological studies are carried out to ensure groundwater protection.

Regulatory and Safety Practices

All nuclear fuel mining and milling operations in India are governed by a stringent regulatory framework to ensure environmental protection and occupational safety [7]. These activities strictly adhere to the safety codes prescribed by the Atomic Energy Regulatory Board (AERB), which regulates radiological protection, operational protocols, and waste management. Additionally, every project undergoes a mandatory Environmental Impact Assessment (EIA) to evaluate potential ecological and social impacts, ensuring that mitigation strategies are implemented before project initiation [8]. UCIL, the principal operator of uranium facilities in the country, maintains compliance with ISO-certified standards for quality, environmental management, and occupational health and safety. This integrated approach reflects India's commitment to sustainable and responsible nuclear fuel resource development.

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