GUIDELINES NO. AERB/FE-FCF/SG-2

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GOVERNMENT OF INDIA

AERB SAFETY GUIDELINES

# RADIOLOGICAL SAFETY IN URANIUM MINING AND MILLING

ATOMIC ENERGY REGULATORY BOARD

AERB SAFETY GUIDELINES NO. AERB/FE-FCF/SG-2

# RADIOLOGICAL SAFETY IN URANIUM MINING AND MILLING

Atomic Energy Regulatory Board
Mumbai-400 094
India

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Price

Orders for this guidelines should be addressed to:

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## FOREWORD

Activities concerning establishment and operation of nuclear facilities and use of radioactive sources are carried out in India in accordance with the provisions of the Atomic Energy Act, 1962. In pursuance of the objective of ensuring safety of members of the public and occupational workers as well as protection of environment, the Atomic Energy Regulatory Board (AERB) has been entrusted with the responsibility of laying down safety standards and framing rules and regulations for such activities. The Board has, therefore, undertaken a programme of developing safety standards, safety codes and related guides and manuals for the purpose. While some of these documents cover aspects such as siting, design, construction, commissioning, operation, quality assurance and decommissioning of nuclear and radiation facilities, other documents cover regulation aspects of these facilities.

Safety codes and safety standards are formulated on the basis of nationally and internationally accepted safety criteria for design, construction and operation of specific equipment, systems, structures and components of nuclear and radiation facilities. Safety codes establish the objectives and set minimum requirements that shall be fulfilled to provide adequate assurance for safety. Safety guides and guidelines elaborate various requirements and furnish approaches for their implementation. Safety manuals deal with specific topics and contain detailed scientific and technical information on the subject. These documents are prepared by experts in the relevant fields and are extensively reviewed by advisory committees of the Board before they are published. The documents are revised, when necessary, in the light of the experience and feedback from users as well as new developments in the field.

Since the industrial safety review of uranium mines is not carried out by AERB, this safety guidelines is aimed to cater to the radiological safety aspects only in uranium mining and milling. AERB safety guidelines on 'Radiological Safety in Uranium Mining and Milling' (AERB/NF/SG/IS-7) provides guidance for ensuring radiological safety in site selection, design, construction, commissioning, operation, maintenance, waste management, decommissioning and controlling of radiation and occupational health hazards of the uranium mining and milling plants. This document is one of the series of guidelines being prepared by AERB to be followed at various stages of uranium mining and milling with an overall objective of protecting the workers and the public from the harmful effects of radiation associated with nuclear fuel cycle facilities. This document addresses administrative, legal and regulatory framework on radiological monitoring, occupational health aspects and emergency plan for mining and processing of uranium. It also provides guidance for the management of decommissioning of such facilities and monitoring and regulatory control during pre-operation, operation, closure and post-closure period.

Consistent with the accepted practice, 'shall' and 'should' are used in the guidelines to distinguish between a firm requirement and a desirable option respectively. References are included to provide further information and clarification on the subject that might be helpful to the user. Approaches for implementation, different to those set out in the guidelines may be acceptable, if they provide comparable assurance against undue risk to the health and safety of the occupational workers and the general public, and protection of the environment.

For aspects not covered in this document, applicable national and international standards, codes and guides acceptable to AERB should be followed.

The Industrial Plants Safety Division of Atomic Energy Regulatory Board has prepared this document. It has been reviewed by specialists in the field and also by the Advisory Committee on Safety Documents related to Fuel Cycle Facilities other than Nuclear Reactors', consisting of experts from the Atomic Energy Regulatory Board, Bhabha Atomic Research Centre, Nuclear Fuel Complex and Heavy Water Board.

AERB wishes to thank all individuals and organisations, who have prepared and reviewed the document and helped in its finalisation. The list of persons, who have participated in this task, along with their affiliations, is included for information.

(S.K. Sharma)
Chairman, AERB

# DEFINITIONS

**Accident**

An unplanned event resulting in (or having the potential to result in) personal injury or damage to equipment which may or may not cause release of unacceptable quantities of radioactive material or toxic/ hazardous chemicals.

**Accident Conditions**

Substantial deviations from operational states, which could lead to release of unacceptable quantities of radioactive materials. They are more severe than anticipated operational occurrences and include design basis accidents as well as beyond design basis accidents.

**ALARA**

An acronym for 'As Low As Reasonably Achievable'. A concept meaning that the design and use of sources, and the practices associated therewith, should be such as to ensure that exposures are kept as low as reasonably practicable, with economic and social factors taken into account.

**Annual Limit on Intake (ALI)**

The intake by inhalation, ingestion or through the skin of a given radionuclide in a year by the reference man, which would result in a committed dose equal to the relevant dose limit. The ALI is expressed in units of activity.

**Approval**

A type of regulatory consent issued by the regulatory body to a proposal.

**Atomic Energy Regulatory Board (AERB)**

A national authority designated by the Government of India having the legal authority for issuing regulatory consent for various activities related to the nuclear and radiation facility and to perform safety and regulatory functions, including their enforcement for the protection of site personnel, the public and the environment against undue radiation hazards.

**Commissioning**

The process during which structures, systems and components of a nuclear or radiation facility, on being constructed, are made functional and verified in accordance with design specifications and found to have met the performance criteria.

**Competent Authority**

Any official or authority appointed, approved or recognised by the Government of India for the purpose of the Rules promulgated under the Atomic Energy Act, 1962.

**Construction**

The process of manufacturing, testing and assembling the components of a nuclear or radiation facility, the erection of civil works and structures, the installation of components and equipment and the performance of associated tests.

**Derived Air Concentration (DAC)**

That activity concentration of the radionuclide in air ($Bq/m^3$) which, if breathed by reference man for a working year of 2000 h under conditions of light physical activity (breathing rate of 1.2 $m^3/h$), would result in an inhalation of one ALI, or the concentration, which for 2000 h of air immersion, would lead to irradiation of any organ or tissue to the appropriate annual dose limit.

**Emergency Exercise**

A test of an emergency plan with particular emphasis on coordination of the many inter-phasing components of the emergency response, procedures and emergency personnel/ agencies. An exercise starts with a simulated/postulated event or series of events in the plant in which an unplanned release of radioactive material is postulated.

**In-service Inspection (ISI)**

Inspection of structures, systems and components carried out at stipulated intervals during the service life of the plant.

**Inspection**

Quality control actions, which by means of examination, observation or measurement determine the conformance of materials, parts, components, systems, structures as well as processes and procedures with predetermined quality requirements.

**Regulatory Body**

See 'Atomic Energy Regulatory Board'

**Responsible Organisation**

An organisation having overall responsibility for siting, design, construction, commissioning, operation and decommissioning of a facility.

**Technical Specifications for Operation**

A document approved by the Regulatory Body, covering the operational limits and conditions, surveillance and administrative control requirements for safe operation of the nuclear or radiation facility. It is also called as "operational limits and conditions".

## SPECIAL DEFINITIONS

(Specific for the present ‘guidelines’)

**Face**

The moving front of any working place or the blind end of any drive, level, cross-cut, raise or winze.

**Incline**

An entry to a mine, that is not vertical or horizontal.

**Landing**

Any floor or platform in a shaft or winze, which is an authorised stopping place of the cage or other means of conveyance.

**Opencast mine**

A quarry, that is to say an excavation where any operation for the purpose of searching for or obtaining minerals has been or is being carried on, not being a shaft or an excavation, which extends below superjacent ground.

**Raise**

A small shaft, either vertical or inclined, developed upwards in the workings below ground.

**Roadway**

Any part of a passage or gallery below ground, which is maintained in connection with the working of a mine.

**Safety Related Unusual Occurrence (SRUO)**

The occurrence of an incident or a plant condition that results in or has potential to lead to fatalities, serious injuries, serious radiation exposure, release of radioactive effluents in excess of permissible limits, release of flammable, toxic liquid or gases resulting in fire, explosion, toxicity etc.

**Shaft**

A vertical or inclined way or opening leading from the surface to working below ground or from one part of the workings below ground to another, and includes an incline.

**Stope**

A stope is an underground workings area inside the mine where extraction of ore is being carried out, except where ore is removed for sinking shafts, driving levels, drifts and other development openings.

**Stowing**

A method of mining in which all the material of the vein is removed and the waste is packed into the space left by the working.

**Support**

Timber-work, masonry, packwalls, sandpacks, iron-work etc. to prevent fall of roof or sidewalls.

**Tailings**

The gangue or waste material separated from useful ore during material processing.

**Ventilating District**

Such part of a mine below ground which has an independent intake of air commencing from a main intake airway and an independent return airway terminating at a main return airway.

**Winze**

A small shaft, either vertical or inclined, developed downwards in the workings below ground.

**Working Level (WL)**

A unit for potential alpha energy concentration (i.e. the potential alpha energy per unit volume of air) resulting from the presence of radon progeny or thoron progeny equal to emission of $1.3 \times 10^5$ MeV of alpha energy per litre of air. In SI units the WL corresponds to $2.1 \times 10^{-5}$ $Jm^{-3}$.

**Working Level Month (WLM)**

The exposure to radon progeny or thoron progeny which would be incurred during a working month (170 hours) in a constant potential alpha energy concentration of one working level. In SI units, a working level month is $3.54 \times 10^{-3}$ $J.hm^{-3}$.

## CONTENTS

# 1. INTRODUCTION

## 1.1 General

This safety guidelines 'Radiological Safety in Uranium Mining and Milling' is prepared under the programme of Atomic Energy Regulatory Board in publishing codes and guides on various topics on nuclear industry [1]. In India uranium ore usually exists in the form of pitchblende ($U_3O_8$) along with the gangue constituents such as quartz, silicates, carbonates, phosphates etc. Mining for uranium is being carried out in the Jharkhand area and exploration in Andhra Pradesh, Karnataka and Meghalaya. Uranium is used as a major fuel in nuclear power generation. Recovery of uranium is carried out in the uranium processing plants (mill) usually situated near the mining area.

Uranium mining may be done by underground as well as open-pit mining methods. As both mining and processing of uranium are associated with them radiological and environmental hazards, it is important that necessary monitoring and control techniques, and safety measures are adopted. This document outlines the various radiological safety aspects related to mining and milling of uranium.

## 1.2 Objective

The main objectives of this 'guidelines' are:

- to lay down the radiological safety requirements for different stages of uranium mining and milling and
- to specify health and radiological safety measures to be taken to protect occupational workers, public and environment during uranium mining and milling.

## 1.3 Scope

Radiological safety measures which should be adopted during mining and milling operation for uranium keeping in view the relevant codes and standards applicable in design, construction, commissioning, operations, maintenance and modifications are discussed in different sections.

Radiological safety aspects to be considered during the mining and milling operation to minimise the exposure to the employees and the public are described along with monitoring programme and control measures for the same. Occupational health aspects are covered in a separate section. Radiological safety measures related to decommissioning and emergency preparedness are also covered.

Management aspects of gaseous emissions, liquid effluent and solid waste are covered in detail in a separate AERB safety guide AERB/NF/SG/RW-5 titled 'Management of Radioactive Waste from the Mining and Milling of Uranium and Thorium'. However a general idea about the same is given in the present document.

# 2. PROCESS DESCRIPTION

Activities for exploration of ore such as geological mapping, estimation of reserves etc. are prerequisites of mining. Based on borehole sampling and geological method of identification, reserves are estimated and ore body geometry is prepared. Uranium ore above the cut-off grade is identified and delineated along rock in the mine based on radiological properties and geological properties of strata.

Before actual mining of an ore body, preparatory activities are carried out which extend over years and are usually known as mine development. Mining of uranium involves activities such as drilling, blasting, loose dressing, mucking and transportation of ore up to the processing plant complying with various safety provisions related to support, ventilation, dewatering etc. Uranium ore is then processed by beneficiation processes involving crushing, grinding, leaching, filtration, purification and precipitation in the processing plant to obtain yellow cake or other suitable compounds.

## 2.1 Mine Development

Mine development is the preparatory activity before the ore winning operation and involves provision of facilities for transportation of men and materials, ventilation, water supply for drilling, making ore passes/man passes, laying of pipelines for water/ compressed air/slurry for void filling, drainage, laying of electrical/signaling cables, installations of winches, electrical substations, mechanical/electrical workshops, magazine rooms, first aid rooms, etc.

Following are the major constructions carried out during the development stage:

Means of Access and Egress : Usually shafts, inclines, adits or combination of these in underground mine and ramps in opencast mine are used as means of access and egress. Adits which are horizontal or nearly horizontal entrance from surface to underground are usually made into the side of a hill or mountain.

Haulage : Haulage roadways are made such that these are suitable to the transportation system. In underground mining, safety manholes are made for the purpose of sheltering at particular intervals throughout the haulage.

Stope : In an underground mine using 'cut & fill' method, stopes are developed for continuous production activities in the identified ore body, divided into different blocks. There are several types of stopes such as shrinkage stopes, room and pillar stopes, sublevel stopes, cut & fill stopes etc.

Ventilation Circuit : In underground mine a network of drives, raises, levels, crosscuts are made for the completion of ventilation circuit and for ensuring supply of air at every working place. In addition to the main fan or fans, auxiliary fans may be used for air supply to a particular working or face.

Sumps : Sumps are excavations made to collect seepage water and are located usually at the bottom of a shaft, near the shaft or at some interior point in underground mine. In open cast mines sumps are located at the bottom most level of the mine.

## 2.2 Mining Operation

The cycle of operation in uranium mining is given in Fig.-1. The major activities taken up during mining operation are as below :

Face preparation for drilling, loose dressing and supporting : Face preparation involves checking of the safety of the working places for carrying out drilling. Loose rock pieces from roof (in underground working), sides and faces are dressed down to prevent any unwanted fall of rock. Rock-bolts, timbers, props etc. are used for supporting rocks.

Marking for drill holes : The locations of drill holes are conspicuously marked to guide drilling. Strength/geology/presence of joints/fractures in the rock, bench height, ore grade, old workings, etc. are considered in planning and execution.

Drilling : Drill-holes at faces, roofs, benches, stopes etc. are made for purposes such as blasting, supporting works like grouting, rock bolting, rope stitching, making boreholes for sampling, exploration, rock instrumentation, laying pipelines and holes for drainage etc.

Charging and blasting : Charging of explosives into holes and blasting operations are required for breaking the hard rock. Blasting is done by use of explosives, detonators and blasting accessories and is carried out by a remote control process, usually by an exploder.

Mucking : Scattered blasted rocks are gathered and the face is prepared according to suitable method of mucking. During mucking, rocks of undesired sizes/relatively big sizes are separated and kept for secondary blasting. Each time a face is advanced or a slice is cut, loose dressing, supporting such as void filling is done. The ore is transported by unloading into ore passes and loading through the ore chutes into tubs/hoppers of rail/trackless transport.

Back-filling : In ‘cut and fill’ mining, using hydraulic stowing, after removal of an ore slice, the void is filled up with de-slimed mill tailings, brought by pipelines to the levels.

Transportation : Blasted muck is sent to primary crusher with the help of transport system such as belt conveyor, rope conveyor, rope haulage, locomotives, trucks etc. Ore is usually transported to mill or to a temporary ore pile and waste rock to a waste dump/stockpile or sometimes accommodated in the mine itself.

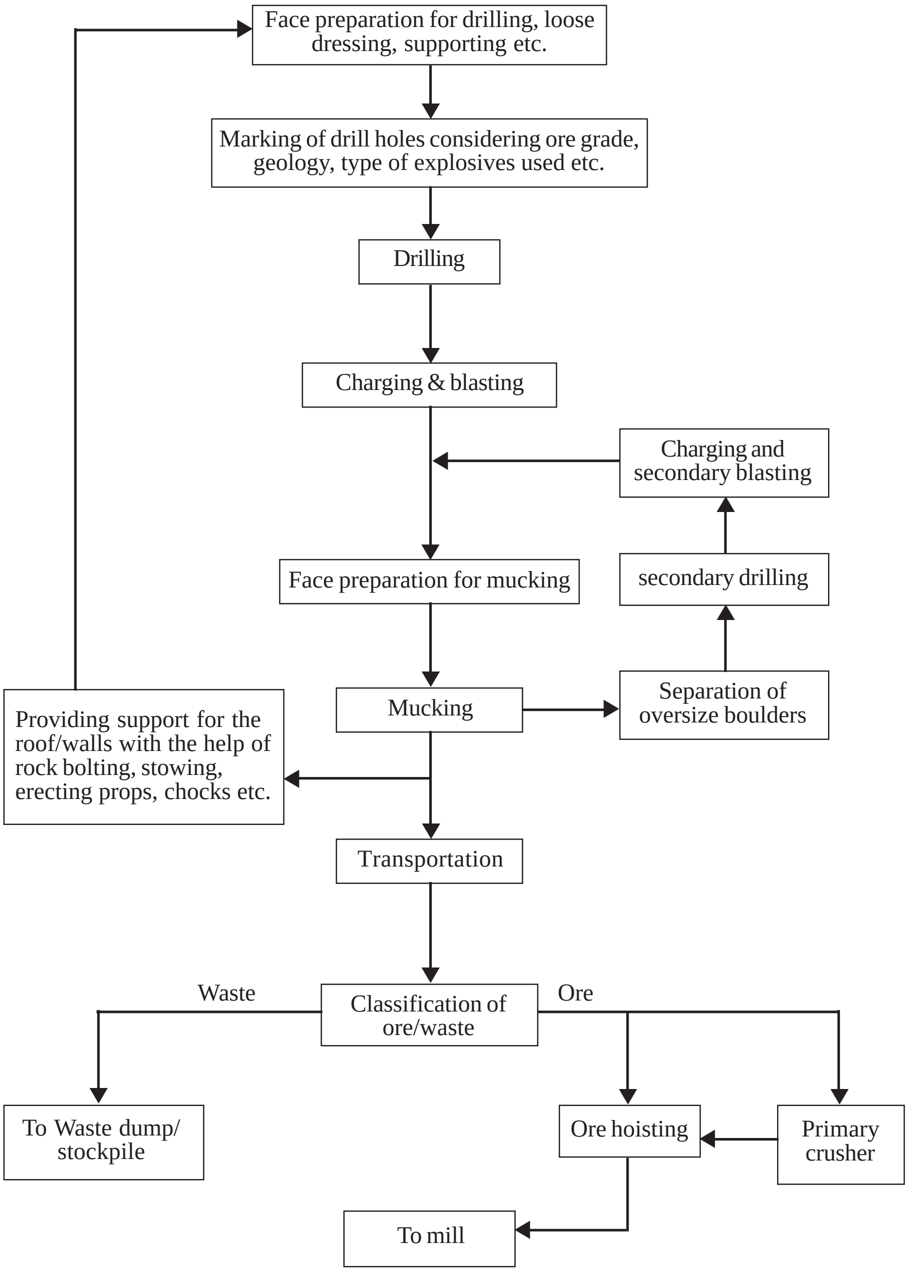



**FIG. 1 : URANIUM MINING OPERATION WORK CYCLE**

## 2.3 Milling Operation

Concentrated uranium compound is obtained from the ore through hydrometallurgical process. The block diagram of milling process is given in Fig. 2. The major activities of milling operation are the following:

Transporting ore : Ore from the mine is transported by conveyor belt or by diesel powered loader equipment to the mill. The large lumps are dumped to the crusher through hopper, bins etc.

Crushing : Crushing is the preliminary size reduction operation involved in milling. Ore size reduction approximately up to 25 mm is carried out in the crusher. Crushing is carried out in steps involving different types of crushers such as jaw crusher, head cone crusher etc. Screens are used to separate out the desired portion for sending it either for fine crushing or for recycle. Fine fraction is sent to the grinding section with the help of hopper, vibratory feeder, belt conveyor.

Grinding : Size reduction in grinding is carried out up to around 200 mesh. The exact size depends on the type of subsequent processes used. Finer the ore, better would be the recovery in leaching. But this would cause difficulty in solid liquid separation after leaching. Major equipment used for grinding are rod mill, ball mill etc. A combination of dry grinding and wet grinding is generally used for size reduction.

Dewatering, filtration, re-pulping are also part of grinding operation to produce slurry suitable for leaching of uranium. Thickener, and disc filters are used for dewatering and making the pulp of required density. The recovered water is reused for grinding.

Leaching : Leaching of the ore is carried out to bring the maximum possible amount of uranium into solution. The type of leaching and the process conditions depend on the composition of the ore. The pulp received after grinding operation is leached with sulphuric acid (acid leaching) or with carbonate/bicarbonate (alkali leaching) at higher pressure. The leaching can be a once through operation or recycle operation. Solid and liquid separation is carried out by filtration.

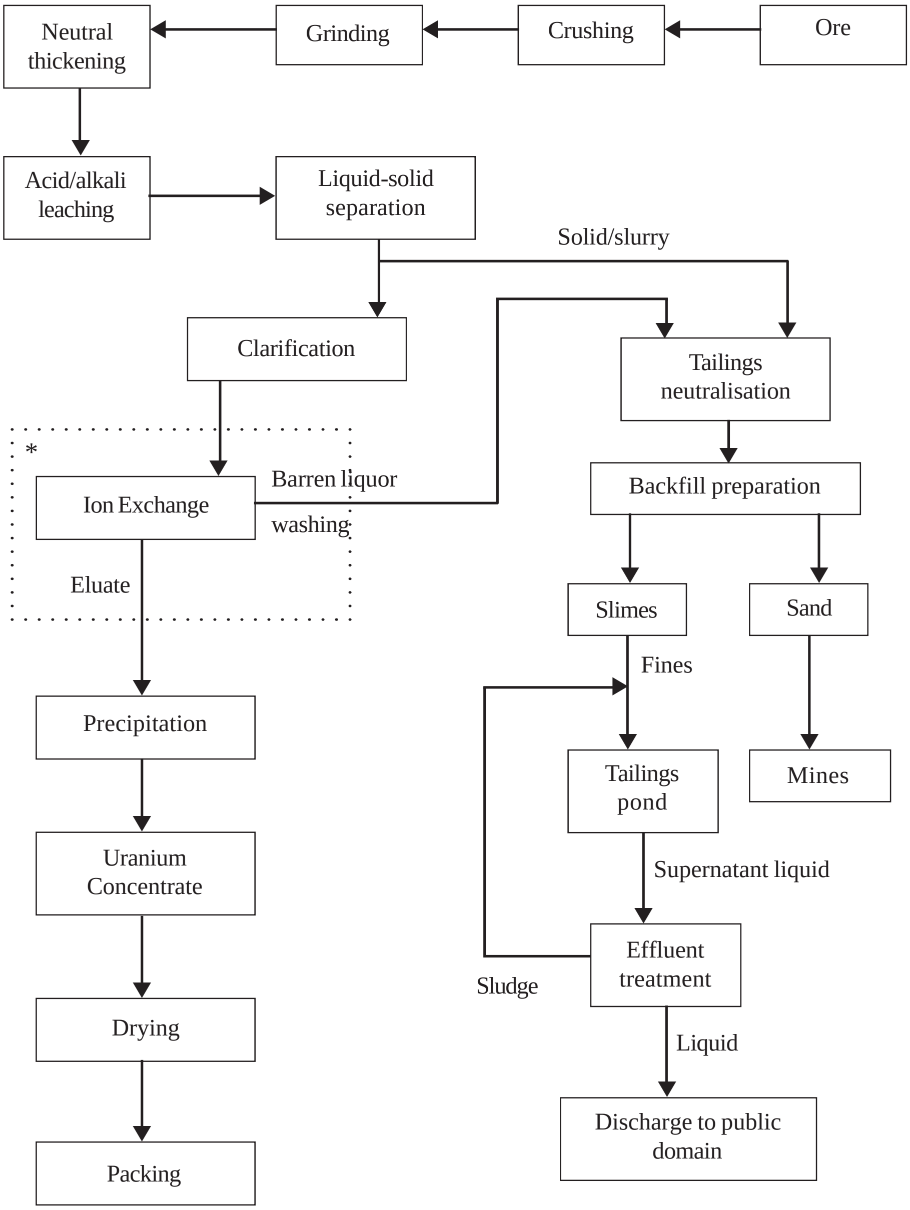
Purification : Leach liquor from primary filter is processed further for uranium purification. The uranium bearing solution from acid leaching is purified by ion exchange process. Uranium is absorbed and impurities are left in the effluent. Elution gives the product solution containing uranium.

Precipitation, Recovery, Drying and Packing : The uranium from the liquor is precipitated (in case of acid leaching) and washed.

The product is recovered either as di-uranate (DU) or carbonate or other suitable compound. The product is dried and packed and is sent for further processing.

Tailings Neutralisation and Impounding: The barren liquor from ion exchange is acidic in nature and contains most of the radium and other radionuclides dissolved in the leaching process as well as traces of uranium. The solid waste from secondary filter cake slurry contains the un-dissolved uranium, radium and other radionuclides. These are neutralised with lime and sent for separation of coarse and fine fractions. The coarse goes to the mine for backfilling and fine to tailings management facility (Tailings Pond).

Effluent Treatment: The decanted liquid from the tailings pond is sent to the effluent treatment plant (ETP) for chemical treatment and removal of dissolved radioactivity before discharging to the public domain as stipulated by the State Pollution Control Board and AERB.




* In case of carbonate process (alkali leaching), 'ion exchange' is not required.

**FIG. 2 : URANIUM MILLING BLOCK DIAGRAM**

## 3. SITE SELECTION

The selection of site for carrying out mining gets restricted to the place of occurrence of the mineral deposit containing uranium. The Atomic Minerals Directorate for Exploration and Research carries out exploration and establishes suitable uranium deposits.

License shall be obtained for opening/operation of uranium mine under the following rules.

- The “Atomic Energy (Working of Mines, Minerals and Handling of Prescribed Substances) Rules, 1984 (from DAE)
- The “Atomic Energy (Radiation Protection) Rules, 2004” (from AERB)
- The “Atomic Energy (Safe Disposal of Radioactive Wastes) Rules, 1987 (from AERB).

All other statutory requirements with respect to mining are to be obtained.

Siting of the processing unit is preferably near the mine and needs review by AERB as it involves radiation safety. The aspects to be considered are provided in the format of site evaluation report (SER) in Annexure-2 of AERB safety guide AERB/NF/SG/G-2 titled ‘Consenting Process for Nuclear Fuel Cycle Facilities Other than Nuclear Power Plants and Research Reactors’. The contents of the SER should cover items under the following broad categories:

**1. Salient features of the proposed site**

(a) Geography, Demography and Topography

(i) The site and its location should be described with the aid of maps of suitable scale. The present and foreseeable uses of surrounding area should be described. Data on food/milk production and on dietary habits in the area should be compiled with special attention to food processing or any other sensitive industry.

(ii) Existing or planned industrial and public facilities in the neighbourhood (5-10 km depending on the hazardous nature of the facility) such as roads, railways, waterways, transport of dangerous goods, chemical plants, military installations, gas pipelines, airports, archaeological monuments and places of pilgrimage, including anticipated changes in their utilisation and distance from the proposed facility should be described in such a way as to facilitate the evaluation of the risks which they may pose to the nuclear facility and vice versa.

(iii) The current and the forecast population of permanent residents in the surrounding area should be tabulated as a function of distance and direction in such a way as to demonstrate the feasibility of emergency plans to protect the population against the accidental release of radioactivity. Similar information should also be given for transient and seasonal population.

(iv) Access to the site should be discussed where it may influence outside intervention in case of emergency, ease of evacuation of personnel or of members of the public, or hazards associated with the shipment of radioactive waste. The topography of the surrounding area and the site should be described.

(b) Meteorology

(i) Meteorological conditions having an influence on the consequences of normal and accidental releases of radioactive/ hazardous materials should be described and discussed.

(ii) The frequency of occurrence and possible consequences of extreme meteorological conditions such as cyclones and heavy precipitation should be discussed.

(iii) The information should include the distribution of wind velocity and direction and atmospheric stability conditions. Annual/ monthly average data on temperature, humidity and rainfall should be included.

(iv) The effect which meteorological conditions have in establishing design bases and operating conditions for the plant should be shown.

(c) Hydrology

(i) Information should be submitted, giving quantity and quality, about the water at and around the site. This information should include, in particular, sources of water and their availability, ground water movement, river or lake current, dispersion conditions, potable and service water supplies.

(ii) Attention should be given to the uses, present and projected water originating in or flowing through the area, taking into account possible contamination by the facility in normal operation and accident conditions.

(iii) Where applicable, the effect of natural phenomena such as tidal effects, floods and coastal cyclones should be evaluated. The consequences of failure of installations such as dams (upstream or downstream) should also be evaluated.

(d) Geology

(i) Information should be provided on the geological formation of the site and its surrounding areas and the effect it may have on the design of the foundations and structures.

(ii) This information should include investigation of surface faulting, stability of sub-surface materials, and stability slopes and embankments. Such features as geological anomalies and underground workings should be identified.

**2. Seismicity**

(a) Information concerning the seismicity of the site and its surrounding area and the method followed for establishing the design basis vibratory ground motions should be discussed and the data given.

(b) This information should include a description of the behaviour of the ground during tremors in the past, a seismic history of the area, an indication and evaluation of the active faults within a significant radius, and data on the seismo-tectonics of the site.

**3. General description of plant covering basic design features, e.g.**

(a) overall safety approach and

(b) codes and standards applicable to the design

**4. Nuclear security**

(a) Impact of site and surroundings on nuclear security and

(b) Physical protection system, physical barrier, communication etc.

**5. Interactions of the facility with its environment**

(a) Radiological and Chemical Impact

(i) All necessary ecological data from the site and its surrounding area that are important for review and assessment of the radiological/environmental impact of the nuclear facility, such as biological systems and critical pathways, should be presented.

(ii) In case such data still needs to be generated, program for the generation of the same may be given. In the mean time conservative assumptions/approaches could be used with respect to the radiological impact. The purpose is to get an assurance that the requirement regarding specified dose limits are met.

(iii) A description of the organisation and conduct of an environmental monitoring program to establish baseline data on radioactivity levels should be given.

# 4. DESIGN

## 4.1 Ventilation System

Design features for mine and mill ventilation are separately described in section 5.

## 4.2 Pumping

During mining, water accumulates due to natural seepage through rock/soil. In order to collect the seepage water, sumps are made inside the mine. Water is utilised in mining activities such as drilling, stowing, water spraying for dust suppression, washing of machinery during maintenance etc. The drainage water from these activities is also collected in sumps. A pumping system is therefore required to avoid overflowing of the sumps and the sump capacity should be sufficient to enable storing of mine water without any overflow of water inside even if pumping fails up to 16 hours.

## 4.3 Material Handling Equipment

All the material handling systems should be so designed and selected that minimum manual handling of the material will be required. The loading and unloading points of conveyors, ore chutes, ore passes, grizzly, transfer points etc. are likely to liberate fine ore dusts to the occupied areas. Appropriate protective measures such as enclosures, water spraying etc. should be provided at such locations to prevent air contamination by escape of respirable dust.

## 4.4 Tailings Management Facilities

The design and construction of embankment system for the storage of tailings slurry should meet the safety criteria of applicable engineering codes with respect to long term stability, particularly against erosion, heavy rain, flood and seismically induced acceleration fields.

Stability analysis for embankments shall be done at various cross-sections of dams under different loading conditions i.e. construction, normal operation and earthquake conditions, at every stage of construction. Strength parameters should be appropriately chosen for foundation rock, tailings, clay, toe fill and random fill. Stability analysis of tailings dam should consider the effect of liquefaction. Under earthquake condition, safety of the dam should also be checked for vibratory ground motion considering liquefaction and also without liquefaction condition. Settlement analysis should also be carried out for tailings dam.

Design of tailings ponds should satisfy required minimum factor of safety (FOS) under all loading conditions. Stability analysis of tailings pond should be carried out using both static and dynamic loading conditions. If the construction of the embankments is carried out in phases, the design checks as mentioned above should be carried out corresponding to each phase of construction.

The permeability of the bed and sides of the tailings management facilities should be maintained below $10^{-9}$ m/s and layers of impervious liners should be used all along the bed and sides to achieve this.

Water management and waste water treatment facilities such as decant water ponds, effluent treatment plant (ETP), monitoring ponds, excess water ponds etc. should be designed to meet the safety criteria of engineering codes with respect to long term stability.

## 4.5 Radiological Safety

The design of the uranium mine/processing plant and equipment shall be such that radiation exposure to occupational workers and members of the public are kept within the dose limits specified by the regulatory body. The exposure should be kept as low as reasonably achievable (ALARA).

Design shall cater to radiation shielding of the equipment to reduce the radiation levels.

Containment of the radioactive material should be one of the important design considerations for the processing facility of uranium. Prevention of spillages of active solutions and product shall be taken care in the design of plant/ equipment. The design and operation of crushing and screening plants should be such as to keep the release of contaminants as low as practicable.

Design of ventilation system shall ensure air activity levels in the plant areas well below the DAC value for radionuclides of concern (preferably 0.1 DAC in full occupancy area).

Control of inhalation hazard due to radon and its daughters is mainly achieved by provision of good ventilation. The external exposure in the mill area can be reduced by administrative control and physical barrier. Control measures should be taken to reduce the spread of radioactivity through air, water and by contamination from waste rock piles, ore stock points, crushers, ore transport at surface, tailings dams, discharge points for final effluents etc.

# 5. VENTILATION DESIGN AND CONTROL

## 5.1 Mine Ventilation

### 5.1.1 Mine Ventilation Design

For open cast mine, forced ventilation is generally not required unless and otherwise specified. The ventilation in the underground mine is maintained by mechanically forced air flow. The requirements of air flow in terms of quantity and quality change continuously inside a mine along with development and the stages of operation. The design of the forced ventilation should consider the changing scenario along with radiological aspects while choosing the capacity and efficiency of a fan for ventilation. The ventilation system should be planned considering the future layout of the workings and the method of workings to be adopted. To achieve maximum efficiency it is essential to eliminate short-circuiting between the intake and return airways, which reduces fresh air flow to the working areas. Thus, ventilation efficiency quotient (VEQ) (i.e., the ratio between the quantity of air reaching the last connection in a ventilating district, and the quantity entering the ventilating district, as measured at the start of the split), achieved from the design, should be maximised. While designing the mine ventilating circuit, the sources of leakage of air should be considered at areas such as surface air locks and fan drifts, pit bottom separation doors and other ventilation doors, ventilation stoppings and air crossings, packs, breaks in strata etc.

Ventilation below ground should be adequate to clear dust and to dilute radon gas so as to render them harmless.

The air activity levels in the mine for radon, its daughters and long-lived alpha emitters should be well below the limits specified by the regulatory body (preferably 0.1 DAC in full occupancy area).

Following general features should be adopted for maintaining effective and adequate ventilation.

- Total area below ground under ventilation should be divided into separate ventilating districts and each such district should have separate intake and return airways from main airway so that contaminated air from one district does not pass through other districts.
- Fans are installed in parallel or in series depending on requirement of air in mine taking into account the resistances incurred. However, parallel-distribution of air to active workings is preferable compared to series-distribution to avoid cumulative air contamination and to minimise resistance to air flow.

- As far as possible intake airways should be located outside ore zones so as to control radon emanation in the general body of mine air.
- Air velocities should be sufficiently high to reduce residence time and radon daughter build up.
- All unapproachable areas including abandoned areas, old workings etc. should be effectively sealed off and should be kept under proper supervision.
- Recirculation of air, as far as practicable, should be avoided to reduce exposure to radon and radon daughters by proper locations of auxiliary or booster fans and suitable arrangements of brattices, doors, stoppings, air-crossings and other such devices.
- Drainage water, particularly from within the ore body, should be kept out of intake airways and working places to prevent the release of dissolved radon into the ventilating air.
- Loose and broken rock should not be allowed to remain underground for long period to minimise radon production.
- In case of electrically driven mechanical ventilator, power should be supplied to the ventilator through a separate circuit from the main distribution point of the mine. Mechanical ventilation fans should be operated continuously. If ventilation is interrupted for a prolonged period, affected areas should be evacuated. Reentry should not be made until restart of ventilation and until radon decay product concentration reduces to permissible values.
- Every mechanical ventilator other than auxiliary fan should be so designed and maintained that the current of air can be reversed in the event of release of radon gas at or near the downcast shaft of a mine.
- Auxiliary fans should be used to distribute adequate fresh air to active workings located off main air-courses. Auxiliary fan should have air duct for conducting the air to or from the face or blind end, and such air duct should be so maintained as to minimise any leakage of air and to ensure an adequate supply of air to within 4.5 meters of the face or blind end.
- In any mine or a part where a mechanical ventilator is used, every drive, cross-cut, winze or a raise which is a connection between main intake airway and a main return airway shall, until it has ceased to be required and has been sealed off, be provided with at least two doors so spaced that whenever one door is opened, the other door can be kept closed. Steps shall be taken to ensure that at least one of the

doors is always closed. Any such connection, which has ceased to be so required, shall be effectively sealed.

- Auxiliary fans shall be located, installed and worked in such a manner that sufficient quantity of air shall, at all times, reach it so as to ensure that it does not recirculate air and there is no risk of contamination to the air which it circulates by any substantial quantity of radon gas or dust.

5.1.2 Mine Ventilation Monitoring

The quantity of air circulating in every ventilation district shall be measured once at least in every 30 days. The radiological and environmental parameters such as ambient radon, long-lived alpha activity in air etc. should be monitored by Health Physics Unit of respective plants.

## 5.2 Mill Ventilation

Equipment and processes producing airborne dust, radon gas and radon daughters should be segregated and enclosed in confinement as far as possible and wherever necessary mechanical exhaust should be used in occupied areas. Administrative measures shall be taken to control the access of workers in contaminated area. The exhaust air should be suitably treated before discharge to the environment.

In order to reduce the dust load, good practices like cleaning and cosmetic maintenance particularly in containment area are to be adopted.

Control measures to protect the health of workers are basically achieved by confinement of the radioactive materials within the process equipment. Fine dust and radioactive gases generated during the processes should not be allowed to escape to occupied zones. For this purpose the equipment/ confinements should be provided with appropriate ventilation to keep the process at a small negative pressure. The processes should be largely automated, thus minimising contact of the workers with radioactive material. The working practices should be designed to reduce the exposure of personnel to the radioactive material both during operation and maintenance.

Complete confinement is essential in the dry material handling and dry concentrate areas. Significant quantity of dust is liberated due to transfer of material from belt conveyors. The entire belt conveyor and especially the transfer points should be provided with appropriate enclosures. Other dynamic processes like air/wind tables where fine dust is liberated should be provided with enclosures. Appropriate enclosure with local exhaust systems having dust collection and scrubbing facilities should be provided in the dust prone uranium milling activities.

All packaging and handling of uranium ore and compounds shall be mechanised to avoid direct handling and exposure. Wherever necessary personal protective equipment (PPE) should be used in such operations.

For areas having limited/unlimited occupancy it is to be ensured that fresh air shower is available for working personnel and contaminated air is removed rapidly from ventilation systems. Attention should be given to prevent formation of dead ventilation zones.

Each product drum filling area should have sufficient exhaust. Exhaust hoods should be connected with the equipment and the airflow should be sufficient to prevent any blow back to the occupied area.

Respirable dust concentration should be kept far below TLV.

# 6. CONSTRUCTION

The development/construction methodology for uranium mine/processing facilities should ensure that the design intents are complied with. Construction activities of any plant should not jeopardize the safety of the adjacent or nearby plants/structures or parts thereof, which have already been constructed.

The organisation responsible for construction should develop and implement a quality assurance (QA) programme, which describes the overall arrangement for the management, performance and assessment of facility under construction. This programme should also provide the means to ensure that all the work is suitably planned, correctly performed, assessed and documented. The quality assurance manual which outlines the basis of the QA programme should be available for review and any check or hold points required by the regulatory body should become a part of the QA plans.

The regulatory consents for the development/construction for uranium mine/processing facilities require the submission of safety analysis reports (SAR)/ safety report (SR) as described under section 4.3 of AERB safety guide AERB/NF/SG/G-2 titled 'Consenting Process for Nuclear Fuel Cycle Facilities other than Nuclear Power Plants and Research Reactors. The safety report is one of the important documents for the regulatory body to determine whether the occupier has taken adequate measures to mitigate the radiological hazards/risk to the plant/site personnel, the public and the environment.

The various aspects to be considered for regulatory consent are given in the contents of safety report in Appendix-I of AERB safety guide AERB/SG/IS-2 titled 'Preparation of Safety Report of Industrial Plants other than Nuclear Power Plants in the Department of Atomic Energy'.

# 7. COMMISSIONING

Reports on commissioning activities should be submitted to the competent authority. All accidents and safety related unusual occurrences (SRUO) having radiological significance should be promptly investigated and reports submitted to the competent authority.

## 7.1 Inspection and Testing

Commissioning programme for uranium mining and milling should include detailed inspection and testing procedures in the sequence in which they are expected to be performed. All commissioning tests should be performed in accordance with approved procedures. Applicable operational limits and conditions along with testing limits and conditions shall be included in the inspection and testing procedure. Required instrumentation and equipment should be specified for the inspection and testing. Radiological safety precautions necessary for the inspection and testing should be clearly mentioned in the commissioning programme. All the inspection and testing data and records shall be maintained in required format. Final inspection and testing report shall be prepared and sent to the competent authority for review.

## 7.2 Training

A training programme shall be established to ensure that personnel involved in the commissioning and operation of mining and milling are trained to attain requisite competence and radiological safety awareness at all levels of the organisation. The effectiveness of the training shall be evaluated by assessment and retraining on periodic basis.

Feedback information on commissioning experience obtained should be used as a part of training programme. Records of training of all personnel shall be maintained.

A separate programme for training of contract employees should be implemented.

## 7.3 Emergency Plan

An on-site emergency plan shall be prepared to take care of any unusual condition or situation with respect to radiological safety. All the persons working in the mine/mill should be familiar with the on-site emergency plan.

# 8. OPERATION

Document on operating procedure shall be made with respect to normal and off-normal operation.

## 8.1 Operating Manual

Operating manual shall be prepared and circulated among the operating personnel for the mining/milling operations. The limiting conditions for operation having radiological significance approved by the regulatory body shall be prepared as technical specifications report. The operating manual/ technical specifications shall clearly indicate the precautions to be taken by workers for their own safety and for the safety of fellow workers, the plant and environment.

## 8.2 Periodic Safety Review

Periodic review of plant performance to identify problems related to radiological safety in operation/systems and equipment are to be carried out by responsible organisation. Reports on safety related unusual occurrences (SRUO) having radiological significance, if any, taking place during operation, dose records, radiological monitoring shall be submitted to the competent authority for review.

# 9. MAINTENANCE

## 9.1 Maintenance Programme

The programme of maintenance of equipment, instrument etc. should be made before commencement of operation. Detailed and up-to-date maintenance schedule shall be prepared. The maintenance requirement supplied by the manufacturers should be considered while preparing the maintenance schedule. The programme should be based on good maintenance practices and to accomplish this, interaction with the designers is required.

## 9.2 Programme of In-service Inspection

In-service inspection manual shall be prepared to assess the health of the equipment/component and to find whether these are acceptable with respect to radiological safety for continued operation. Record of in-service inspection should be maintained for the life of the plant.

## 9.3 Maintenance Data and Record

Information on maintenance from designers, manufacturers and from other operating facilities should be used for making the maintenance schedule. The data on operation and maintenance should also be preserved so that it is helpful for review and modification. In addition, records such as equipment history cards and the results of maintenance experience should be used effectively as input to a continuing review of maintenance schedule and procedures, to ensure component reliability.

# 10. MODIFICATIONS

**10.1 Necessity of Modification**

Modifications based on operational experience in the uranium mining and milling plant or other similar plant or new developments in the technology should be implemented as per approved procedures after ensuring operational safety of the plant. Modifications may affect structures, systems and components, operational limits and conditions, instructions and procedures or a combination thereof.

Where a proposed modification is likely to affect radiological safety, a further independent review and assessment shall be carried out and the proposed modification shall then be submitted to the regulatory body for prior approval.

**10.2 Submission of Proposals**

Proposals for modifications submitted by the responsible organisation for independent assessment shall specify the functional and radiological safety requirements of the proposed modifications and show how these requirements are met. The modification proposal shall demonstrate the improvement over the previous system.

For major modifications, revised safety reports shall be submitted to the regulatory body.

**10.3 Implementation of Modifications and Updating of Records**

All reviews and assessments shall be documented and only those modifications that have successfully gone through the appropriate process and approval should be implemented.

All documents such as operating manual, technical specifications, on-site emergency plan, radiation protection manual, drawings, and P&I diagrams shall be updated according to the modifications carried out. The responsible organisation, after implementing the modifications, should update the records.

# 11. RADIOLOGICAL SAFETY

## 11.1 Introduction

In uranium mine, the radiation hazard is primarily from exposure to airborne radionuclides and to a lesser extent from external radiation. The airborne radionuclides consist of radon and short-lived radon daughters, which are of major concern and long-lived alpha emitters, which are present in the mine atmosphere in the form of dust. The concentration of airborne radionuclides is higher in underground mine than in the opencast mine where inhalation hazard is usually of minor concern.

In uranium mill the impact of radon and its daughters is less pronounced than in underground mine. But airborne radioactive contamination in the form of long-lived radionuclides is likely to result from processing of the ore. External radiation assumes significance in concentrate handling areas.

Safety directives prescribing the dose limits for occupational exposures to ionising radiations are issued by Chairman AERB from time to time.

Principal decay scheme of the uranium series along with the half lives of radioactive products is shown in Fig. 3

## 11.2 Uranium Mine

### 11.2.1 Airborne Radioactivity

(a) Radon and its daughters

The hazards in uranium mine arise from the inhalation of radon and its daughters and from long-lived alpha emitters present in mine atmosphere associated with airborne dust. The primary airborne radionuclides are $^{222}$Rn and its short-lived daughters $^{218}$Po (RaA), $^{214}$Pb (RaB), $^{214}$Bi (RaC) and $^{214}$Po (RaC). The magnitude of the dose depends on the concentration of the daughter products in the inhaled air as well as physiological parameters.

Radon is released in the mine atmosphere by diffusion and percolation through the ore body. Radon emanation is continuous inside the mine unlike that of ore dust, which is produced only during mining operations. A common source of radon is water percolating through the ore body, dissolving the radon gas to a considerable extent and then releasing it into the mine atmosphere through the roof and walls of the mine.

Radon daughter atoms originally exist singly in the air but in a short time attach themselves to atmospheric aerosols, mine walls and other m

surfaces. Those radon daughters, which become attached to aerosols, follow the behavior of these particles or nuclei. Since most radon daughters get attached to particles with ˜0.3 mm in diameter all the daughter products become respirable. The unattached radon daughters are deposited mainly in the trachea of the respiratory tract. Exposure limits recommended by International Commission on Radiological Protection (ICRP) take this feature into consideration.

Short-lived radon daughter products i.e. $^{218}$Po, $^{214}$Pb, $^{214}$Bi and $^{214}$Po are always present with $^{222}$radon in atmosphere. They are highly mobile and tend to attach to any available surface. When inhaled, they attach to different compartments in lung. Because of very short half-life, all the above mentioned daughters decay completely to $^{210}$Pb before any translocation from lung takes place. Therefore the total alpha energy released by individual daughter and other subsequent daughters is imparted to the lungs. For this reason a special unit called ‘working level (WL)’ is specified for radon daughters’ concentration. It corresponds to potential alpha energy concentration of 1.3 x $10^5$ MeV/litre (20.8 µJm$^{-3}$). Cumulative exposure to radon daughters is measured in terms of working level month (WLM), which corresponds to exposure to 1 WL concentration for 170 working hours.

For convenience of operation, radon concentration is routinely monitored in mines. A predetermined equilibrium factor (F) is used to convert absolute radon concentration ($Rn_{abs}$) to equilibrium equivalent radon concentration ($Rn_{EER}$). It is given by

$$Rn_{EER} = Rn_{abs} \times F \quad ; \quad WL = Rn_{abs} \times F/3700$$

The International Commission on Radiological Protection recommends an annual limit of intake (ALI) by inhalation of $^{222}$Radon daughters of 0.02 J of inhaled potential alpha energy. This corresponds to cumulative exposure of 4.8 working level month (WLM) and derived air concentration (DAC) of 8.3 µJ.m$^{-3}$ or 0.4 working level (WL).

(b) Long-lived Radionuclides

Uranium ore contains all isotopes of $^{238}$U and $^{235}$U chain. From the viewpoint of internal contamination, the long-lived, alpha emitting nuclides $^{238}$U, $^{234}$U, $^{230}$Th, $^{226}$Ra and $^{210}$Po are significant. Mining operations consisting of drilling, blasting, crushing etc. produce airborne dust containing these long-lived nuclides which in most ores are close to radioactive equilibrium. The ventilation that is required for control of radon and radon daughters also keep the levels of these long-lived nuclides considerably below the applicable concentration limits.

11.2.2 External Radiation

Uranium miners are exposed to external beta and gamma radiations emitted from the ore bodies. However, only the gamma radiation is of significance in considering the risk of external exposure. The gamma radiation field will depend upon the grade of the ore and can be expected to be higher, when the ore is stockpiled.

11.2.3 Surface Contamination

Owing to the nature of operations in uranium mine, dust particles are generated and the wetness in the mine and the operational methods adopted help the dust to deposit and also to lose contact from the surface on which it is deposited. Normally dust particles are not hazardous from the radiation point of view, except as a source of air contamination, when they get re-suspended. Surface contamination can assume significance when high-grade ore is extracted. Equipment from the mine should be checked for contamination before it is released outside for maintenance.

**11.3 Uranium Mill**

11.3.1 Airborne Radioactivity

In uranium mill, radon and its daughters usually present only a minor inhalation hazard compared to ore and uranium dusts, although significant radon concentrations may occur near ore storage bins, crushing and grinding circuits.

Operations like ore crushing, grinding and final product preparation by virtue of being dust generating in nature have a potential for creating airborne activity. During crushing and grinding, the long-lived airborne radionuclides, uranium, $^{230}$Th, $^{226}$Ra, $^{210}$Po, tend to be in equilibrium. But, during subsequent operations this equilibrium is necessarily disturbed and the concentration of individual radionuclides must be measured for the assessment of hazards. After leaching of the crushed ore, most of the radionuclides except uranium remain with the waste cake, which after filtration, is sent for tailing treatment. Thus airborne uranium is predominant in the filtration, precipitation and recovery section, since the solutions and solids handled here are rich in uranium. In tailings treatment area, the airborne radionuclides are predominantly Ionium ($^{230}$Th), Radium and Polonium.

In areas where crushers, screens and transfer points generate dust, dust control techniques such as wetting the ore and use of dust enclosures and exhaust ventilation should be employed. Vacuum equipment should be used for clean up work. Use of protective clothing and respirators is necessary especially at the final packaging section. Gloves, aprons etc. should be used for protection against contamination of the skin with uranium.

11.3.2 External Radiation

The exposure of workers in uranium mill to external beta and gamma radiation is generally comparable to the exposure of workers in uranium mine. The gamma radiation fields may vary from mill to mill depending on ore grade as well as type of process. During mill operation, intermediate and final products and radium may accumulate in pipes and tanks and give rise to locally elevated radiation fields. Generally, external radiation hazards assume significance mainly in the final stages of precipitation, filtration, concentrate packaging and storage.

Freshly separated uranium is primarily alpha emitter but as daughter products build up, both beta and gamma activities also build up. The beta-gamma activity reaches about 50% of equilibrium activity in 24 days. Thus in the product storage area, the radiation levels increase with time of storage of the product. The maximum beta/gamma activity is reached in about 240 days and thereafter remains steady.

The radiological hazards/exposure arising can be controlled by the following measures.

- Proper layout that reduces external dose rates to workers by separating their normal workplaces from places where radioactive material accumulates viz. in drying and packaging area and storage area for drums filled with concentrates of yellow cake or other compound.
- Minimising exposure time of workers near the concentrated liquor.
- Using personal protective equipment during handling of radioactive substances
- Adequate ventilation to reduce radon exposure
- Provision of isolated location and barriers for process vessels, equipment which might get coated with gamma emitting radioactive materials and which are the source of external radiation.
- Appropriate location of ventilation opening to remove the contaminants away from breathing zone.

11.3.3 Surface Contamination

Surface contamination can contribute to airborne activity through re-suspension if it is not controlled by proper containment and regular housekeeping. This could be a significant problem mainly where concentrates are handled such as in the precipitation, filtration, weighing and packing areas. Tailings treatment areas are also susceptible to surface contamination.

## 11.4 Personal Protection and Job Rotation

Appropriate respirators should be used to avoid inhalation of airborne dust. AERB safety guidelines AERB/SG/IS-3 titled 'Personal Protective Equipment' should be followed.

Job rotation is recommended as one of the means of regulating external exposure in areas where no other practical means of control are available.

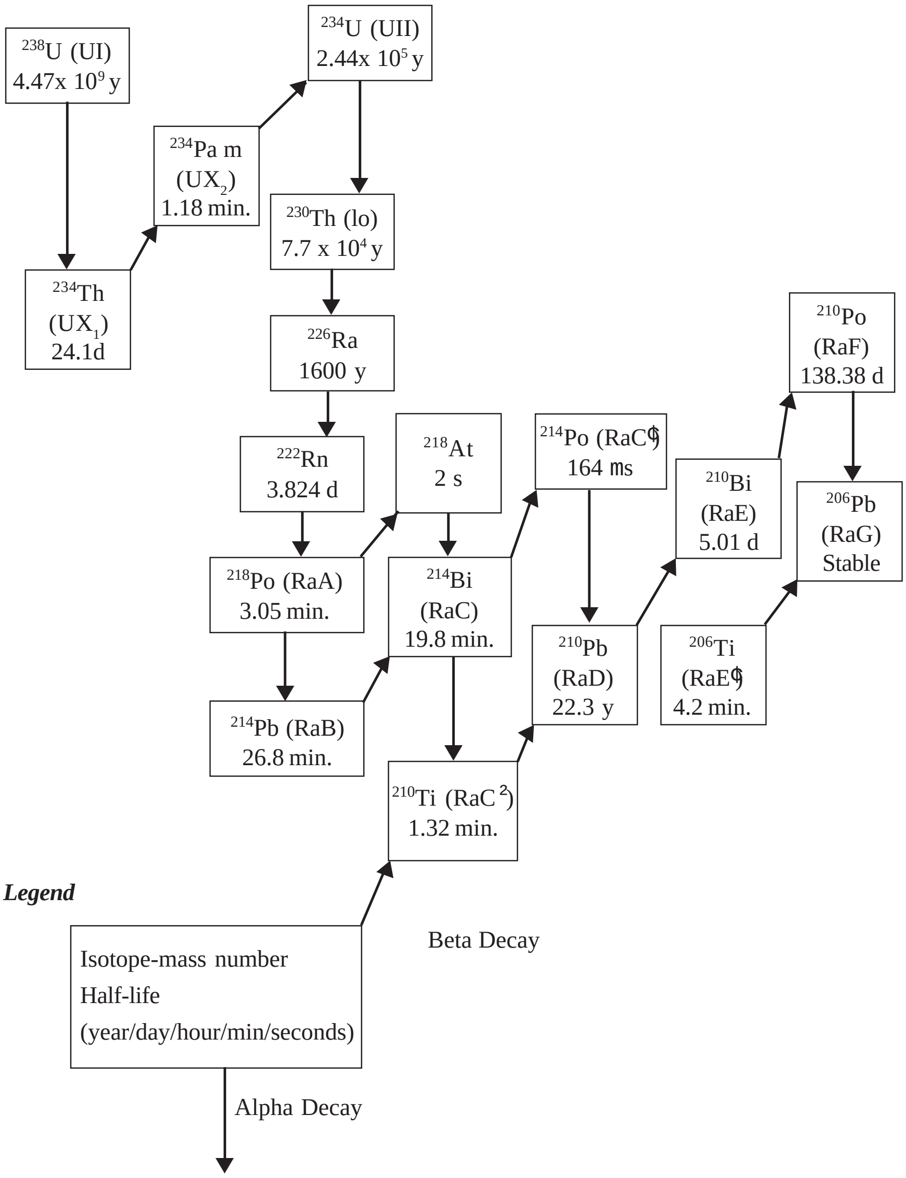



**FIG. 3: PRINCIPAL DECAY SCHEME OF THE URANIUM SERIES ALONG WITH THE HALF LIVES OF THE NUCLIDES**

# 12. RADIATION MONITORING

## 12.1 Monitoring Programme

The purposes of radiation monitoring in uranium mine and mill are:

- to maintain records of personal radiation exposure and radionuclide intake,
- to demonstrate compliance with the regulations governing radiation exposure and intake of radionuclides, and
- to provide information for efficient engineering of the ventilation and radiation control systems.

In order to achieve the purposes outlined above, the following types of monitoring should be carried out:

- Concentration of radon and radon daughters in air
- Personal radon daughter exposures utilising integrated personal radon dosimeter.
- Concentrations of long-lived alpha emitting radionuclides in airborne dust.
- Gamma dose rate
- Personal gamma exposures, utilising integrated personal gamma dosimeters.

All instruments should be properly calibrated and used according to specifications.

## 12.2 Uranium Mine

### 12.2.1 Monitoring of Radon and Radon Daughters

As radon daughters constitute the most significant radiation hazard in the underground uranium mine, it is essential that proper measurements of their concentrations in the air are made.

Air samples should be collected in:

(i) working places with locations so chosen as to ensure that the sample is representative of the air breathed by the workers and

(ii) other appropriate places in the mine as means of engineering assessment of the ventilation and radiation control systems.

The frequency of air sampling should be such as to enable reliable evaluation of the individual internal exposure for each worker. The usual method of calculation is to multiply radon daughter concentrations in the air by the duration of stay in the place at this concentration.

Personal radon daughter dosimeters for obtaining integrated exposures have been developed as a reliable device (e.g. instruments using nuclear track detectors of polycarbonate or cellulose nitrate) and their use is recommended, because personal dosimetry gives the best estimate of individual exposures.

12.2.2 Monitoring of Long-lived Alpha Emitters

Monitoring of long-lived alpha emitters in the air should be carried out in the mine. If the concentration of these alpha emitters is greater than 25% of derived air concentration (DAC), it is recommended that analysis be carried out for uranium, $^{226}$Ra and $^{230}$Th to determine the radioactive equilibrium. If the ore is out of equilibrium, ore dust ALI and DAC should be recalculated.

Dust samples from area samplers should be analysed periodically for gross alpha activity or total uranium to confirm that the concentrations are below the DACs.

Personal sampling instrumentation must work at two stages, with a cyclone or impactor used to separate the coarser non-respirable fraction from the respirable portion, which is collected on a filter. Analysis for gross alpha activity should be done after the radon daughters have decayed.

The exposure of individual workers to long-lived alpha emitters can also be measured by personal air samplers used on the body in addition to calculations based on area sampling and occupancy time. The personal sampler integrates the worker’s exposure for an appropriately chosen period. The sampler or the detector is analysed after the exposure period to yield either cumulative or average exposure, as required.

12.2.3 Monitoring of Gamma Radiation

Monitoring of personal gamma exposures of individual workers should be carried out with personal gamma dosimeters. The most suitable personal dosimeter for the harsh mine environment is thermo-luminescent dosimeter (TLD).

For the purpose of radiation control, regular gamma dose rate monitoring should be undertaken in designated locations, utilising an appropriate and calibrated dose rate meter. Ionization chamber or Geiger counter or scintillation detector could be used for the measurement of gamma radiation field.

## 12.3 Uranium Mill

In uranium mill the radiation exposures to workers are from external gamma and beta radiation and also from internal contamination arising from inhalation and ingestion of the radioactive materials processed. In contrast to the uranium mine, radon and its daughters usually pose only a minor problem in the mill.

### 12.3.1 Monitoring of Internal Contamination

The primary sources of internal contamination in uranium mill are the crushing and grinding sections and the final product precipitation, drying and packaging sections.

Monitoring should be done with personal and area dust samplers. The material collected on the filter by the sampler should be analysed for long-lived alpha activity.

To compute the average internal exposure of a worker, breathing zone samples must be collected for all potentially dust producing operations and general area samples in all other areas occupied by workers. Another method to determine the internal exposure of mill workers is by utilising an individual personal air sampler.

A programme for regular urine sampling of exposed workers of uranium mill should be in place to record the occurrence of uranium intake. Urine analysis is usually limited to workers who are likely to be exposed to uranium concentrates and thus only mill workers need to be considered. Urine analysis provides a ready check on the occurrence of recent internal contamination.

### 12.3.2 Monitoring of External Radiation

External exposures should be monitored using personal dosimeters, the most suitable one being thermo-luminescent dosimeters (TLD).

In addition, the gamma dose rate monitoring of the operational areas should be undertaken for assessment of safety and radiation hazards control.

### 12.3.3 Monitoring of Surface Contamination

Areas where concentrates are handled such as precipitation, filtration and packaging sections require monitoring of surface contamination levels. Tailings treatment areas are also susceptible to surface contamination and require monitoring.

## 12.4 Radiation Exposure Records

Records of internal and external radiation and bioassay in respect of individual worker shall be maintained during employment and also after the cessation of work as specified in the Atomic Energy (Radiation Protection) Rules, 2004.

### 12.5 Environmental Monitoring

A suitable environmental monitoring programme should be established to assess the impact of the mining and milling operations on the environment. The programme may include:

(i) TLD monitoring in the vicinity of the mine and mill for assessment of increase, if any, in the background radiation levels;

(ii) Monitoring of water bodies such as river, stream or lake, into which the low level liquid effluents, after treatment, may be discharged, though within the authorised limits;

(iii) Monitoring of ground water from wells within as well as outside the plant premises;

(iv) Analysis of soil samples from appropriate locations for radioactivity content; and

(v) Airborne radioactivity outside the plant premises.

Based on the analysis of the above data proper assessment can be made on the environmental impact of mining and milling operations.

## 13. OCCUPATIONAL HEALTH SAFETY

### 13.1 Pre-employment Medical Examination

Pre-employment medical examination shall be carried out to provide information on the general health of the worker, to find the suitability of the worker for the job and also to reveal subsequent changes which may be related to his/her occupational exposure. The type of medical examination should be as per AERB guidelines AERB/SG/IS-4 titled 'Guidelines for Pre-employment Medical Examination and Fitness for Special Assignments'.

### 13.2 Periodic Medical Examination

Periodic medical examination shall be carried out based on The Atomic Energy (Working of the Mines, Minerals and Handling of Prescribed Substance) Rules 1984 and The Atomic Energy (Radiation Protection) Rules 2004. The medical tests to be carried out should be commensurate with the hazards such as exposure to dust and radiation. The periodicity and type of medical examination should be as specified by statutes.

### 13.3 Medical Examination at Termination and Follow-up

All persons who have worked in mine and mill should undergo a medical examination upon termination of their employment. If required, further follow-up depending upon the results of the examination should be carried out.

# 14. WASTE MANAGEMENT

## 14.1 Introduction

Safety codes and guides issued by AERB on waste management namely 'Management of Radioactive Waste' (AERB/SC/RW) and 'Management of Radioactive Waste from the Mining and Milling of Uranium and Thorium'(AERB/NF/SG/RW-5) shall be followed.

Wastes in three forms i.e., solid, liquid and gaseous are generated in the process of mining and milling. All the three types may contain radioactive pollutants. All discharges should be allowed only after suitable monitoring to check the effectiveness of the waste management control.

Tailings from the ore processing operations contain radioactive substances. Proper site selection for tailings pond keeping in view low soil permeability coupled with good quality of construction and operating procedure can ensure that the impact of tailings on the health, safety and environment would be acceptably low. For radioactive waste disposal, the responsible organisation shall obtain authorisation from the competent authority under the Atomic Energy (Safe Disposal of Radioactive Wastes) Rules, 1987.

However, general aspects on management of waste from mine and mill are described below:

## 14.2 Mine Waste

### 14.2.1 Solid

The waste rock generated during mining having very low uranium content should be segregated and dumped in identified locations with proper confinement against leaching. Administrative control of using it for other purposes should also be taken.

### 14.2.2 Liquid

The mine water that is not utilised in mining and milling operations should be treated and disposed off conforming to the norms for disposal of radioactive pollutants.

### 14.2.3 Gaseous and Particulate

The gaseous and particulate matter from an underground mine should be discharged in such a manner that the public is not exposed to unacceptable levels of radiation.

## 14.3 Mill Waste

### 14.3.1 Solid

The coarse fraction of the tailings from the mill after leaching should be used in the underground mine for stowing.

The fines generated from the mill tailings after solid-liquid separation is sent to tailings pond in the form of slurry where the solid containing major amount of radium gets settled. The decanted liquid is taken to the ETP for treatment and the sludge generated in ETP is also disposed off in the tailings pond. Due care should be taken for the retention of radioactivity within the pond by providing impermeable lining.

### 14.3.2 Liquid

The decant solution from the tailings pond is treated in the ETP. The quality of the treated effluent from the ETP should be monitored to ensure that it meets the prescribed discharge standard and then only released to the environment.

### 14.3.3 Gaseous and Particulate

All processes generating dust should be provided with exhaust ventilation systems. Filters, scrubbers or other air cleaning devices should be installed to reduce the discharge of airborne contaminants to meet the discharge norms.

Gaseous radioactive effluents released through air route should be monitored and release should be in compliance with authorised limits.

## 15. DECOMMISSIONING

The decommissioning of the uranium mine and mill is different from other mines and chemical industries because it involves the removal of the radioactive contaminations/ substances leading to generation of wastes in solid/liquid form.

The tailings from uranium mining and milling operation remain beyond the operating phase of the facility. Detailed plan has to be made for decommissioning of tailings pond.

The decommissioning plan should outline the procedure for decontamination of equipment, procedure for storage of wastes generated therein and its disposal and proposed usage of the decontaminated equipment. The approval of the competent authority should be obtained for the above. In the case of tailings pond the scheme for remediation of the site and its release for unrestricted use by the public should be prepared and submitted to the competent authority for approval.

### 15.1 Mine

After the useful life of the mine is over, it should be closed. Contaminated plants, equipment and structural materials should be decontaminated and wastes generated should be disposed off in accordance with approved procedures. Waste rock piles and waste retention systems should be left in a stable form so that they blend aesthetically with the general landscape. The piles should be returned to an appropriate land use by re-vegetation or by other means. Measures should be taken to protect the public from any radiological hazard presented by the piles.

### 15.2 Mill

Wastes generated from decontamination of plants, equipment and structural materials should be disposed off in accordance with approved procedures. Areas should be controlled and warning signs should be posted so as to restrict public access/habitation and to prevent their unauthorised use. The levels of radiation from the stabilised waste materials should not exceed those in applicable approved standard. A surveillance and monitoring programme should be established.

### 15.3 Tailings Pond

The approved remediation procedure including growth of appropriate vegetation should be followed and surveillance and monitoring programme in and around tailings pond area should be in place. On completion of these measures, release of this site for unrestricted public use can be considered with the approval of competent authority.

Reports on decommissioning activities and safety related unusual occurrences (SRUO) having radiological significance, which may take place during decommissioning shall be promptly submitted to the competent authority.

# 16. EMERGENCY PREPAREDNESS

## 16.1 Basis for Emergency Planning

The responsible organisation is required to prepare the on-site emergency plan and make the workers aware of their roles during an emergency. The safety measures required to be taken in the event of an accident having radiological safety significance taking place should be outlined in the plan. The AERB safety guidelines AERB/SG/EP-3 titled 'Preparation of Site Emergency Preparedness Plans for Non-Nuclear Installations' is to be followed while preparing the on-site emergency plan for the mill.

The failure scenarios of tailings dam should be worked out and an off-site emergency plan should be prepared in consultation with the district authority, if required.

## 16.2 Emergency Crew

Emergency crew should be adequately qualified through training, empowered with the necessary authority and equipped with adequate resources.

## 16.3 Emergency Training and Drill

The emergency plans should provide for training and testing of individuals or organisational units necessary to assure and demonstrate that they are qualified and able to completely fulfill their assigned emergency preparedness and response roles.

## 16.4 Emergency Facilities and Equipment

The emergency plans should have resources such as communication, mechanism for announcement, monitoring and sampling of releases, emergency shelters at the facility, first-aid facilities, clean up facility, security points, mechanism for distribution and administration of antidotes where applicable, transport, vehicles and fuel, fire fighting facilities/personnel, hospital facilities, rescue teams, site emergency management group, mutual aid, emergency control center and emergency equipment.

Against each of the above, details about the quantity or number, the locations and specifications shall be provided. The designated officials who have the official authority to draw upon these resources should be clearly indicated. The system for periodic testing, maintenance and replacement of equipment (in case of obsolescence) should be described and the responsibility for its implementation should be indicated.

## 16.5 Activation and Termination of Emergency Responses

The emergency plan should describe the procedures for initiating and terminating responses to emergencies associated with facility operations.

## 16.6 Public Information Systems

The emergency plan should include appropriate provisions to communicate pertinent information to the public during an emergency and it should take care to prevent speculation and rumors. The plan should also take into account any need for education of the public with respect to the emergencies at the facility and their implications.

## 16.7 Special Requirements

For the installations in the coastal area, cyclone emergency management plan should be available and it should be prepared in accordance with the guidelines published by the national safety council for the preparation of cyclone emergency management manual for coast-based industrial installations.

Emergency plan should be considered for the sites with long period ground waves during earthquake. The plan should also include the extent of flooding that could take place at the site due to heavy precipitation.

## REFERENCES


1. Atomic Energy Regulatory Board, Regulation of Nuclear and Radiation Facilities, Safety Code (AERB/SC/G), Mumbai, India (2000)
2. Atomic Energy (Working of Mines, Minerals and Handling of Prescribed Substances) Rules, 1984
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