Safety in thorium mining and milling

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OUTLINE

➤ Introduction

➤ Hazards: Conventional and Radiological

➤ Applicable Legislations

➤ Regulatory Control by AERB

➤ Safety measures and Impact of regulatory oversight

➤ Conclusion
## Agencies Involved

Thorium (nat) > 1000kg is Prescribed Substance under the Atomic Energy Act, 1962

Only units of DAE are permitted to extract thorium

<table>
<thead>
<tr>
<th>Exploration:</th>
<th>Atomic Minerals Directorate for Exploration and Research (AMD), Govt. of India</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mining &amp; Milling:</td>
<td>Indian Rare Earths India Limited (IREL), Public Sector Undertaking</td>
</tr>
</tbody>
</table>
Thorium Mines And Mills

Manavalakurichi
(mining and mineral separation)

Thorium Mines And Mills

OSCOM
(mining, mineral separation and chemical processing)

MoPP-project

Chavara
(mining and mineral separation)

Udyogamandal
(chemical processing)

HPRE-project
Composition of Ore

Monazite: Thorium ore

<table>
<thead>
<tr>
<th>Constituents</th>
<th>(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ThO$_2$</td>
<td>8.9</td>
</tr>
<tr>
<td>Re$_2$O$_3$</td>
<td>60</td>
</tr>
<tr>
<td>P$_2$O$_5$</td>
<td>27</td>
</tr>
<tr>
<td>U$_3$O$_8$</td>
<td>0.35</td>
</tr>
<tr>
<td>CaO</td>
<td>0.5</td>
</tr>
<tr>
<td>MgO</td>
<td>0.1</td>
</tr>
<tr>
<td>Fe$_2$O$_3$</td>
<td>0.2</td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
<td>0.1</td>
</tr>
<tr>
<td>PbO</td>
<td>0.18</td>
</tr>
<tr>
<td>Insolubles</td>
<td>3</td>
</tr>
</tbody>
</table>
THORIUM MINING

Beach Sand Mining (Quartz and heavy minerals like Ilmenite, Rutile, Leucoxene, Garnet, Sillimanite, Zircon & radioactive Monazite [source of Th and sec. Source of U])

Pre concentration of heavy minerals

heavy minerals separation (magnetic and electrostatic separators)

Quartz rich sands
THORIUM MILLING

Solid Waste

Th stream

Th.Oxalate

Thorium Nitrate/Thorium Oxide

Thorium Concentrates (after caustic lye attack of monazite)

Acid Dissolution

Solvent Extraction

U stream

Purification

ADU

Solid Waste

Silos
CONVENTIONAL HAZARDS... 1/2

Sinking of the dredge

Drowning of persons

Electrical hazards from high tension separators

Exposure to magnetic field from high intensity magnetic separators
Mechanical hazards from material handling equipment

Inhalation of silica dust

Storage of bulk chemicals and gas cylinders

Use of flammable liquids
RADIOLOGICAL HAZARDS

High energetic alpha emitters source of internal exposure

Thoron and its progeny - source of internal exposure

Very Strong Gamma emitter: 2.64MeV-source of external exposure
Regulation of THORIUM Mines & MILLS
What is regulation?

Control (Supervise /Oversee etc) backed by rules

External Control (Regulatory Body)

Internal Control (Self Regulation)
Regulation of Thorium Mine

IREL → AMD

State Govt. → AMD → MOEF → DAE

Prospecting

Mining Lease

Approval of Mining Plan

Environmental Clearance

Handling prescribed substance

AERB (radiation safety)

DGMS (mine safety)

Mine Development

Operation

Renewal: 5 yrs

Decommissioning

Mine Development

Operation

Progressive closure: 5 yrs

Mine Closure
Mines and Minerals (Development & Regulation) Act, 1957
Mineral Conservation and Development Rules, 1988
Mine Concession Rules, 1960

- Mines Act, 1952

- Environment Protection Act, 1986
- EIA Notification, 2006

Empowers AMD
(prospecting and approval of mine plan)
Empowers State Govt
(mining lease)

Empowers DGMS
(Mine Safety)

Empowers MoEF
(Environmental clearance)
Atomic Energy Act, 1962

Empowers DAE
(to issue license for handling prescribed substance after obtaining NOC from AERB)

Empowers AERB
(to issue consents for mine development and operation and decommissioning)
(to issue authorisation for safe disposal of radioactive wastes)

- Atomic Energy Act, 1962
- Atomic Energy (Radiation Protection) Rules, 2004
License from Chief Controller of Explosives under the Explosive Act 1884 and Rules

License from Boilers Inspectorate under the Indian Boilers Act 1923

Consents from State Pollution Control Boards under the Water (Prevention & Control of Pollution) Act, 1974 and Air (Prevention & Control of Pollution) Act, 1981 - for discharge of non-radiological pollutants
How AERB regulates?

- Specifies requirements in form of Codes, Guidelines etc
- Reviews and Assesses the hazards
- Issues licences
- Monitors and enforces Compliances

Unique features:
- Not by the letter of the rule but by spirit of the rule
- Judgment based on scientific understanding
- Prime responsibility for safety lies with the owner
Specifying limits

Dose limits and constraints

- **Worker**
- **Public**

For thorium milling, AERB directed that individual radiological doses should be within 6 mSv.

<table>
<thead>
<tr>
<th></th>
<th>ICRP recommended limits</th>
<th>AERB prescribed limits</th>
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<tbody>
<tr>
<td><strong>Occupational Worker</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 years</td>
<td>100 mSv (annual average 20 mSv)</td>
<td>100 mSv (annual average 20 mSv)</td>
</tr>
<tr>
<td>One year</td>
<td>50 mSv</td>
<td>30 mSv</td>
</tr>
<tr>
<td>Life time</td>
<td>1000 mSv</td>
<td>1000 mSv</td>
</tr>
<tr>
<td><strong>Public</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One year</td>
<td>1 mSv</td>
<td>1 mSv</td>
</tr>
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Safety review process

Extent of review commensurate with the hazard involved.

As per established codes and guides

Multi tier review Process
  Fair, just and reasonable
  Independent
  Non-Subjective
  Comprehensive
  Broad based

Safety Review Committees: experts from AERB, DAE units, IITs, MoEF, Academic Institutions etc.

Participation of stake holders
From cradle to grave

Siting
↓
Construction
↓
Commissioning
↓
Operation
↓
Decommissioning
To verify that licensee complies with national safety requirements and the consenting conditions.

Inspections include scheduled and reactive inspections, both announced and unannounced.
Regulatory Inspections of operating Mines and Mills:

Inspections performed in accordance with magnitude and nature of associated hazard (graded approach)

<table>
<thead>
<tr>
<th>Thorium Mines &amp; Mineral Separation Plants</th>
<th>Once in a year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thorium Mills</td>
<td>Twice in a year</td>
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</table>

• Quarterly inspection for milling projects w.r.t construction safety
Areas Covered

- Implementation of recommendations / stipulations of Safety Committees/AERB
- Compliance with AERB Safety Codes/Guides,
- Fire and Industrial Safety measures
- QA
- Adherence to Tech specs
- Training and Qualification
- Radiation Protection and Waste Management procedures
- O&M aspects
- Occupational Health
- Safety Culture, etc.
Waste Management

Authorisation under Atomic Energy (Safe Disposal of Radioactive Wastes) Rules, 1987

Waste discharge/storage limits on activity and volume for
  - Solid
  - Liquid
  - Gaseous

Filing of periodical returns to AERB
Effluents Release Criteria

Basis of Control – Public dose limit 1 mSv from all sources from a site.

- This is roughly equal to one-third the radiation dose that Indians may receive annually from natural sources.
- It is within the variation of the dose received from natural sources.
- This is also the limit recommended by ICRP and adopted by almost all countries in the world.
**Effluents Release Criteria**

**Dose Apportionment:**

- 20 – 30% of 1 mSv is kept as reserve dose for future.

- Remaining Fraction of 1 mSv is apportioned to various facilities and the apportioned dose is subdivided to different pathways and then to various radionuclides.

- Apportioned doses are translated into discharge limits for each radionuclide and specific concentrations based on environmental dose assessment models and site specific parameters.
Pathways of Radiation Exposure to Public

Radioactive Effluents

Nuclear Facilities

Gaseous deposition

Inhalation and direct exposure

Water Body

Crops/Vegetables

Animal (meat/milk)

Fish

Ingestion
Health Physics Unit: radiological monitoring of the workers, work atmosphere, waste discharges and the surrounding environment.

Occupational Health Centre: Periodic Medical Examinations of the workers as per regulatory requirements.
Specific Safety Requirements for thorium mining and milling
### Major Concerns

**External events: cyclone and tsunami**

**Bulk quantities of hazardous chemicals**

- Acids and Alkalis
- Organic solvents/diluents
- Flammable liquids (furnace oil)

**Large throughput of radioactive material (thousand tons per day)**

**Large volume of low active alpha bearing waste (thousands cubic metre)**

**Chronic but persistent low radiation levels**
Relevant Regulatory Safety Documents

Safety Code on Regulation of Nuclear and Radiation Facilities
Safety Code on site evaluation of Nuclear Fuel Cycle Facilities
Safety Guidelines on thorium mining and milling
Safety Guidelines on Management of Radioactive Waste from Uranium and Thorium Mining and Milling
Safety Manual for Radiation Protection in Nuclear Facilities
SAFETY MEASURES

Ventilation: to ensure toxic and noxious gases does not exceed permissible limits.

Dust minimisation: water spraying, sprinklers, appropriate enclosure with negative pressure, local exhaust systems having dust collection, scrubbing/filtration facilities

Noise control: at source (low noise machines, isolating the noisy machines etc) during transmission (noise absorbing structures)
Fall Protection (thorium mines):

- Preventing sinking of dredge by maintaining a 250mm minimum free board
- Restricting dredge operation up to a maximum wind speed of 90km/hr so as to avoid its destabilising due to cyclone.
- Provision of railings, nylon nets and chains throughout the path from the shore to the dredge, integrity tests of the pontoons and availability of buoys and life jackets

Extreme wind load considered during design of new monazite processing plant at Odisha coast which could withstand the impact of recent cyclone Phailin.
## SAFETY MEASURES

### Internal radiological exposure
- Ventilation
  - Layout and zoning
- Confinement and containment (enclosures)
- PPEs administrative

### External radiological exposure
- Time (access control) – supervised area/controlled area
- Shielding
- Distance administrative

- Dose constraint: 6mSv/year
Average Individual Dose in thorium mines & mills over the years

<table>
<thead>
<tr>
<th>Facility</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>UDYGAMANDAL</td>
<td>5.61</td>
<td>4.31</td>
<td>4.56</td>
<td>2.34</td>
<td>0.89</td>
<td>0.84</td>
</tr>
<tr>
<td>CHAVARA</td>
<td>0.29</td>
<td>0.44</td>
<td>0.42</td>
<td>0.49</td>
<td>0.44</td>
<td>0.64</td>
</tr>
<tr>
<td>MK</td>
<td>6.46</td>
<td>5.82</td>
<td>5.75</td>
<td>2.85</td>
<td>1.22</td>
<td>1.50</td>
</tr>
<tr>
<td>OSCOM</td>
<td>1.16</td>
<td>1.15</td>
<td>0.94</td>
<td>0.66</td>
<td>0.60</td>
<td>0.94</td>
</tr>
</tbody>
</table>
SAFETY MEASURES

Management of Solid Wastes from thorium milling

Lead barium cake (500-1000Bq/g) – engineered FRP lined concrete trenches
Iron carbonate cake (500-1500Bq/g) - engineered FRP lined concrete trenches
Monazite insoluble (400-500 Bq/g) – engineered FRP lined concrete trenches
Sedimented sludge from ETP (100-200 Bq/g) – earthen trenches

Monitoring wells all around the waste disposal yard. No noticeable increase in concentration of radionuclides observed till date.
SAFETY MEASURES

Long term Management of thorium oxalate

Storage in engineered concrete silos

Storage in engineered trenches

- Leachability- alkaline pH (online monitoring)
- Treatment of supernatant in ETP
- Design of trenches- migration studies of thorium in ground water
- Environmental surveillance
Cyclone Preparedness

- Cyclone Preparedness Plans
- Cyclone warning
- Communication
- Response and rescue operations
- Mock exercises

Cyclone preparedness successfully demonstrated at IREL Chatrapur, Odisha during cyclone Phailin.
Private Players

BSM Policy, 1998: To boost up the mineral exploitation of non-strategic minerals and to encourage participation of private players in the field of beach sand mining and mineral separation.

Permitted to mine out heavy minerals from beach sands other than monazite.

This results in generation of monazite rich tailings.
AERB’s regulatory control on the private players

Safety Guidelines on ‘Radiological Safety in Processing of BSM and other NORMS’

License under RPR, 2004

Approval of Radiological Safety Officers

Periodic Safety Review: periodic health physics reports, safety issues

Regulatory Inspection
Management of Monazite rich tailings

Objective: the natural background radiation should not be elevated due to disposal/storage of monazite rich tailings

Large quantities and monazite content < 5%: mixed with silica sand and backfilling the mined out site

Small quantities and monazite content >5%: stored in trenches and topped with silica sand
Concluding Remarks

The three tier safety review process and periodic regulatory inspections involve continuous interaction between the facility and the regulatory body.

This regulatory framework has been effective enough in achieving high safety standards in the fuel cycle facilities including Thorium mining & milling.
“Radioactive material and sources of radiation should be handled in Atomic Energy Establishment, in a manner, which not only ensures that no harm can come to workers in the Establishment or anyone else, but also in an exemplary manner so as to set a standard which other organization in the country may be asked to emulate”.

- Homi Jehangir Bhabha, 1960

Thank You