IAEA Technical Meeting
Amman, Jordan

Uranium Exploration and Mining Methods

Radiation Safety Aspects in the Uranium Production Cycle
Overview

- Overview of uranium in mining and processing.
- Radiological characteristics.
- Potential health effects.
- Importance of advanced planning for an integrated Safety Culture in the project life cycle.
- Exposure pathways of Workers and the Public.
- Overview of the Radiation Protection Programme.
- Waste management.
- Tailings Siting and Design.
Uranium Mining and Processing

- A variety of methods are used e.g. open pit, underground and ISL.
- A wide variety of ore grades are exploited.
- Can be produced as by-product e.g. gold and copper mines in South Africa.
- Uranium and its residues are radioactive and emit ionizing radiation and are therefore potentially harmful to workers and the public.
- Long term issues with the tailings and waste rock after closure.
- Requires a Planned Lifecycle Safety Culture.
- Public concerns regarding safety.
Uranium and Radiation

- Uranium is a radioactive element
- It emits alpha, beta and gamma radiation
- Long half life of 4.5E9 years
- It is a primordial form of NORM
- In nature it is found in equilibrium with its 13 decay products (e.g. $^{226}$Ra, $^{210}$Po etc) and decays to stable lead
- Uranium product comprises $^{238}$U, $^{234}$U, and $^{235}$U in their natural proportions
- Uranium product is a poison, its chemical toxicity damages the kidneys
\[ ^{238}\text{U decay chain} \]

\[ 238^{\text{U}} \rightarrow 234^{\text{Th}} \rightarrow 234^{\text{mPa}} \rightarrow 234^{\text{U}} \rightarrow 230^{\text{Th}} \]

\[ 214^{\text{Bi}} \rightarrow 214^{\text{Pb}} \rightarrow 218^{\text{Po}} \rightarrow 222^{\text{Rn}} \rightarrow 226^{\text{Ra}} \]

\[ 214^{\text{Po}} \rightarrow 210^{\text{Pb}} \rightarrow 210^{\text{Bi}} \rightarrow 210^{\text{Po}} \rightarrow 206^{\text{Pb}} \]

Stable
The Decay and Emissions of Important Radionuclides of the \(^{238}\text{U}\) Decay Chain

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Half-life</th>
<th>Mode of Decay</th>
</tr>
</thead>
<tbody>
<tr>
<td>U-238</td>
<td>(4.5 \times 10^9) years</td>
<td>alpha</td>
</tr>
<tr>
<td>U-234</td>
<td>(2.4 \times 10^5) years</td>
<td>alpha</td>
</tr>
<tr>
<td>Th-230</td>
<td>(7.7 \times 10^4) years</td>
<td>alpha</td>
</tr>
<tr>
<td>Ra-226</td>
<td>(1.6 \times 10^3) years</td>
<td>alpha</td>
</tr>
<tr>
<td>Pb-210</td>
<td>22.3 years</td>
<td>beta</td>
</tr>
<tr>
<td>Po-210</td>
<td>138 days</td>
<td>alpha</td>
</tr>
</tbody>
</table>

Note: Alpha emitters are a significant internal hazard.
Radiation and Radioactivity

- Radioactivity is the property of certain materials to emit ionising radiation
- There are three principal types of ionising radiation:
  - alpha
  - beta
  - gamma radiation and also X-radiation (which is artificially produced)

Uranium ores and product materials emit all three types of radiation
Radiation Quantities and Units

The quantities and units used in radiation protection and safety are based on the SI system for scientific units and are developed by the International Commission on Radiological Units (ICRU).

The main quantities of interest include:

- Activity e.g. the Becquerel (Bq)
- Dose e.g. the Sievert (Sv)
Alpha particles travel only a few centimetres in air and are incapable of penetrating the skin. Beta particles have a range of more than one metre in air and up to one centimetre in tissue. Gamma rays can be very penetrating. They can pass through the walls of plant and equipment.
Harmful Effects of Radiation

- The damaging effects of ionizing radiation became apparent only a few years after the discovery of radiation (X-ray researchers burns and cancers).

- Extensive research carried out in many countries around the world has enabled increasingly detailed estimates of the effects of low doses of radiation to be made.

- Numerous studies indicate elevated lung cancer rates in underground miners.
## Estimated Loss Of Life Expectancy From Health Risks

<table>
<thead>
<tr>
<th>HEALTH RISK</th>
<th>ESTIMATED MEAN DAYS OF LIFE EXPECTANCY LOST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overweight by 20%</td>
<td>985</td>
</tr>
<tr>
<td>Auto accidents</td>
<td>200</td>
</tr>
<tr>
<td>Smoking 1 cigarette/day</td>
<td>118</td>
</tr>
<tr>
<td>Alcohol consumption (US average)</td>
<td>130</td>
</tr>
<tr>
<td>Home accidents</td>
<td>95</td>
</tr>
<tr>
<td>20 mSv/year for 30 years (calculated)</td>
<td>60</td>
</tr>
<tr>
<td>Safest jobs (such as teaching)</td>
<td>30</td>
</tr>
<tr>
<td>Natural background radiation (calculated)</td>
<td>8</td>
</tr>
<tr>
<td>Medical X-rays (calculated from US average)</td>
<td>6</td>
</tr>
<tr>
<td>Exposed Population</td>
<td>Annual Effective Dose (mSv)</td>
</tr>
<tr>
<td>--------------------</td>
<td>----------------------------</td>
</tr>
<tr>
<td>Worker</td>
<td>5</td>
</tr>
<tr>
<td>Public</td>
<td>0.25</td>
</tr>
</tbody>
</table>
Nominal Cancer Risk

Another way of expressing the risk is to assume that if a group of 1,000 individuals were exposed, how many would be expected to develop a cancer during their lifetime?

Workers: a total of 5 individuals would be expected to develop cancer.

Public: a total of 0.3 individuals would be expected to develop a cancer.

Approximately 41% of the US population will develop a cancer during their lifetime.

A total of 70% of all cancer mortalities occur after the age of 65.
Establishing a Safety Culture

• Radiation is **one of many risks** associated with uranium mining.

• A Safety Culture requires to be established at an early stage in the lifecycle of a project to control the risks to acceptable levels.

• Responsibility at **Board Level** to drive the process.

• Requires a competent well resourced **Regulatory Authority**.

• **Compliance with Dose Limits.**
Establishing a Safety Culture

• An integrated management approach is required in order to ensure the optimisation of the overall Health, Safety and Environment Programme.

• The RPP forms an important part of the Health and Safety Management culture.

➢ Requires advanced planning for safety.
➢ Requires designing for safety.
➢ Requires ongoing training.
Timelines: Facility Lifespan

Regulatory

Impact of waste

Planning

Eng. Options

Site, Des. & Const.

Waste Man. Plan

Monitoring: Pre-op

Monitoring Ops

Decom. Closure & Controls

Mon. & Surv

Exploration

IAEA

Planning

Construction and Operation

Decommissioning

Handover & Surveillance

Quality Assurance

Health and Safety

Uranium Exploration and Mining Methods
## Annual Dose Limits

<table>
<thead>
<tr>
<th>Type</th>
<th>mSv.y⁻¹</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workers</td>
<td>20 (av)</td>
<td>Above background*</td>
</tr>
<tr>
<td></td>
<td>(100 over 5 years)</td>
<td></td>
</tr>
<tr>
<td>Public</td>
<td>1</td>
<td>Above background</td>
</tr>
<tr>
<td>Alara</td>
<td>As low as reasonably achievable</td>
<td>Economic and social factors taken into account.</td>
</tr>
</tbody>
</table>

Natural background (2.4 mSv.y⁻¹)
## Variation in Activity Concentrations

<table>
<thead>
<tr>
<th>Material</th>
<th>$^{238}\text{U}$ (Bq.g$^{-1}$)</th>
<th>$^{226}\text{Ra}$ (Bq.g$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ore (130 ppm)</td>
<td>1.61</td>
<td>1.61</td>
</tr>
<tr>
<td>Waste rock</td>
<td>0.456</td>
<td>0.456</td>
</tr>
<tr>
<td>Tails</td>
<td>0.248</td>
<td>1.61</td>
</tr>
<tr>
<td>Product</td>
<td>12380</td>
<td>0</td>
</tr>
<tr>
<td>Scales (pipes, vessels, filter cloths, HDPE)</td>
<td>&lt;1-12380</td>
<td>&lt;1-50000</td>
</tr>
<tr>
<td>Natural soils</td>
<td>0.02-0.03</td>
<td>0.02-0.03</td>
</tr>
</tbody>
</table>
Human Exposure Pathways

- **External exposure**
  
  External exposure e.g. from gamma emitters in stockpiles and wastes e.g. ore, tailings and waste rock.

- **Internal exposure**
  
  Internal exposure e.g. ingestion and inhalation (radon gas, radon progeny and dusts) of alpha emitting materials e.g. open pit, mills, tails, product section.
Occupational Exposure

• Can occur at any part of the lifecycle (e.g. from exploration to closure).

• Increases with ore grades.

• Higher exposures tend to occur in underground operations (e.g. radon) compared to open pit.
Worker and Public Exposure

- Exploration and prospecting teams.
- Construction crews.
- Workers at the open pit mining operations.
- Drivers transporting ore.
- Workers at the process plant.
- Drivers transporting uranium product.
- Workers at the mine site involved in the tailings and waste rock disposal operations.
- Visitors to the operations.
- Contractors working at the Project.
- Members of the public who live close to the mining and processing operations.
Occupational Exposure

In surface operations exposures occur at:

- Open pit.
- Stockpiles.
- Crushers and mills.
- Leach section.
- Product section.
- Tailings operations.
- Maintenance operations.
- Decommissioning and closure.
<table>
<thead>
<tr>
<th>Exposure Pathway</th>
<th>Radiation Type</th>
<th>Exposure Locations</th>
</tr>
</thead>
<tbody>
<tr>
<td>External</td>
<td>Gamma radiation</td>
<td>Ore body, ore, tailings, waste rock. Leaching section, precipitation, product section and stores.</td>
</tr>
<tr>
<td>External</td>
<td>Beta radiation</td>
<td>Uranium product packing section.</td>
</tr>
<tr>
<td></td>
<td>Gamma radiation</td>
<td>Uranium product store and transport.</td>
</tr>
<tr>
<td>Internal:</td>
<td>Dust: Long-lived alpha and</td>
<td>Uranium product packing section. Dry sections of the operations (e.g. mine, milling, tailings).</td>
</tr>
<tr>
<td>inhalation</td>
<td>beta emitters</td>
<td></td>
</tr>
<tr>
<td>inhalation</td>
<td>Radon gas and decay products</td>
<td>Underground-Open pit.</td>
</tr>
</tbody>
</table>
Public Exposure

• Public exposure results from:
  • Discharges to air and water from:
    • Mining operations
    • Stockpiles.
    • Residues and wastes e.g. tailings and waste rock.
    • Contaminated scrap.
Overview of Public Exposure Pathways
## Public Exposure Pathways

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<thead>
<tr>
<th>Exposure Pathway</th>
<th>Radiation Type</th>
<th>Exposure Locations</th>
</tr>
</thead>
<tbody>
<tr>
<td>External</td>
<td>Gamma radiation</td>
<td>Fallout dust accumulating in the surface soils downwind of the tailings, ore and waste rock dumps.</td>
</tr>
<tr>
<td>Internal: inhalation</td>
<td>Long-lived alpha and beta emitters</td>
<td>Dusts released from the mine/pit, tailings, ore and waste rock rock dumps and the calciner stack.</td>
</tr>
<tr>
<td>Internal: inhalation</td>
<td>Radon gas and decay products</td>
<td>Radon gas released from the mine/pit, tailings, ore and waste rock rock dumps.</td>
</tr>
<tr>
<td>Internal: ingestion</td>
<td>Long-lived alpha and beta emitters</td>
<td>Through the consumption of groundwater that has been contaminated by seepage from the tailings, ore and waste rock rock dumps.</td>
</tr>
</tbody>
</table>
Radiation Protection and the Project Timelines

The various radiation protection aspects require to be planned for long before implementation:

- Exploration and prospecting
- Construction
- Commissioning
- Operation
- Waste management
- Closure and remediation

NB: A variety of safety assessments and radiological impact studies require to be carried out at various stages of the project.
Administrative Controls

- Radiation Protection programme.
- Records.
- QA and QM.
- Access controls.
- Protective clothing.
- Respiratory protection.
- Training.
Engineered/Design Controls

• Design of the plant to keep doses Alara.

• Dust control systems (open pit, crushers and mills).

• Ventilation systems.

• Product packing (ventilation, dust controls and automatic interlocks).

• Physical Security.
Radiation Protection Programme (RPP)

• The extent of the RPP is always tailored to the level of radiation risk to workers and the public arising from a specific project.

• The RPP and its associated controls are primarily concerned with control over the areas containing radioactive materials and the way humans interact with these radiation sources.

• The requirements of a RPP are clearly documented in a set of approved documents.

• The documents will comprise Programmes, Plans, Procedures, Records, Schedules, Reports and Electronic Databases.
Components of the RPP

• Safety assessments to determine the level of risk to workers and the public.
• Engineered and Administrative controls.
• The Occupational Radiation Protection Programme.
• The Public Radiation Protection Programme.
• Workplace monitoring programmes.
• Individual monitoring and a dosimetry programme for OEPs.
• A radiation training programmes for workers.
Components of the RPP

• Medical surveillance for OEPs.
• Health and dose registers for OEPs.
• Effluent and environmental monitoring programmes.
• The Waste Management programme.
• The Occurrence Reporting and Emergency Plan Programme.
• The Quality Management and Assurance Plan.
• The Site Decommissioning and Closure Plan.
• The Physical Security Programme.
• Transport Programme.
• The Radiation Protection GIS System and Database.
WASTE MANAGEMENT AND DISPOSAL OPTIONS

• The siting and design of the tailings is a critical issue. As there are long term implications for the public and the environment (e.g. legacy sites).

• The radiological implications and options require to be assessed at an early stage of the project.

• All radioactive waste streams require to be identified and characterized.
Tailings Impacts

- Human & Animal Intrusion
- Radon & Gamma Radiation
- Dust Blowing (Radium, Arsenic, ...)
- DAM FAILURE
  - Erosion
  - Flood
  - Earthquake
  - Structural
- Seepage
  - Arsenic, Uranium, Radium...
Summary

• Uranium is a naturally occurring radioactive material (NORM).
• It emits ionizing radiation in the form of alpha, beta and gamma radiation.
• Human exposure to radiation involves both internal and external exposure pathways.
• Radiation doses require to be limited to reduce the risk of harmful effects.
Summary

- Exposure to ionizing radiation can occur at any point in the mine lifecycle.
- Higher ore grades mean higher exposures.
- A variety of administrative and engineered controls are used to limit exposures.
- Occupational and public doses must be kept ALARA.
- The siting and design of tailings is critical.
- Planning for Safety must begin at an early stage of the project.
Thank You

CABINET 1: URANIUM SAMPLES