Monitoring, surveillance and environmental radioactive impact associated to the mining of Uranium

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Outline

- Uranium mining
- Mine life-cycle
- Waste produced and radiological impact
- Radiological monitoring and surveillance
- Remediation of legacy sites
  - History and cases- lessons learned
- Future of uranium mining
Uranium production: the first step of fuel cycle

1. URANIUM EXTRACTION
   Uranium: 1-200 kg U/ton ore
   Dissolved in acid or alkali, extracted and dried - Yellow cake 99.27% 238 and 0.7% 235U

2. CHEMICAL CONVERSION
   The Yellow cake is purified and converted into hexafluoride. 235U is enriched up to 5%.

URANIUM ORE extracted in open pits or underground mines. Radon gas is the main radiological hazard. Low grade ores are extrated in situ with acid (in situ leaching).
Uranium mining and milling:
How it looks like

Ore extraction

U chemical extraction

Yellow cake

Wastes
Life-cycle of an uranium mine

- **Prospection:**
  - identification of ore deposits
  - assessment of deposit value and extraction costs

- **Mining:** extraction of the ore
  - mine operation: underground/open pit
  - transport of the ore
  - ore processing

- **Close out of the mine**
  - safety requirements
  - environmental remediation
Uranium ore

Isotopic composition of natural uranium:

<table>
<thead>
<tr>
<th>Isotopes</th>
<th>$T_{1/2}$ (years)</th>
<th>% Mass</th>
<th>% Activ</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{238}\text{U}$</td>
<td>$4.5 \times 10^9$</td>
<td>99.285</td>
<td>48.9</td>
</tr>
<tr>
<td>$^{235}\text{U}$</td>
<td>$7.1 \times 10^8$</td>
<td>0.710</td>
<td>2.2</td>
</tr>
<tr>
<td>$^{234}\text{U}$</td>
<td>$2.5 \times 10^5$</td>
<td>0.005</td>
<td>48.9</td>
</tr>
</tbody>
</table>

Secular radioactive equilibrium

$1 \text{ g uranium} = 25.28 \text{ kBq}$
Uranium Ore Processing

- On mining site or off-site
- Ore crushing
- Acid leaching 
  \((H_2SO_4)/carbonate\)
- Acid solution ⇔ solvent extraction ⇔ recuperation of uranium ⇔ production of yellow cake \((U_3O_8)\)
- WASTE containing radionuclides
  - Acidic waters
  - Solid waste (mill tailings)
WASTE WATERS:
Acid mine waters and Process waters

- Large volumes
- Low pH (1-3), high sulphate ion conc
- Often treated: neutralized with hydroxide, and $^{226}$Ra and U co-precipitated with BaSO$_4$
- Decantation in ponds:
  - overlaying water released into streams or pumped back into the mine
  - Decanted sludge pumped as a slurry into dewatering ponds (evaporation); mud contains high U, Ra, Po, etc.
SOLID WASTE:
Mill tailings

- Fine sands, high specific activity of $^{226}$Ra, $^{230}$Th, $^{210}$Pb, $^{210}$Po, …
- Low concentrations of uranium
- May contain stable metals, eg., As, Y, Bi, Fe, Cu, etc
- and sludge (mud) from water treatment
RADIOACTIVITY in soils and mine waste

Bq/kg (dry weight)

<table>
<thead>
<tr>
<th></th>
<th>238U</th>
<th>235U</th>
<th>234U</th>
<th>230Th</th>
<th>226Ra</th>
<th>210Po</th>
<th>232Th</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mill Tailings, Mina da Urgeiriça Barragem Velha</td>
<td>2530</td>
<td>118</td>
<td>2880</td>
<td>10340</td>
<td>24720</td>
<td>20350</td>
<td>410</td>
</tr>
<tr>
<td>Ore M. Ureiriça. Descarga do minério-</td>
<td>38320</td>
<td>1720</td>
<td>38250</td>
<td>30115</td>
<td>15570</td>
<td>30820</td>
<td>425</td>
</tr>
<tr>
<td>Mill Tailings Mina da Cunha Baixa (Mangualde)</td>
<td>2030</td>
<td>90</td>
<td>2280</td>
<td>3600</td>
<td>6700</td>
<td>4700</td>
<td>460</td>
</tr>
<tr>
<td>Mill Tailings Mina da Bica (Sabugal)</td>
<td>10700</td>
<td>480</td>
<td>11400</td>
<td>30000</td>
<td>50000</td>
<td>29000</td>
<td>180</td>
</tr>
<tr>
<td>SOIL Espinho (Mangualde)</td>
<td>230</td>
<td>10</td>
<td>236</td>
<td>301</td>
<td>619</td>
<td>287</td>
<td>226</td>
</tr>
</tbody>
</table>
## Ambient dose rate

### Dose equivalent, mSv per year

<table>
<thead>
<tr>
<th>GE</th>
<th>Counties</th>
<th>Dose</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><em>Canas Senhorim</em> county (outside mining area)</td>
<td>2.4</td>
</tr>
<tr>
<td></td>
<td><strong>Mill tailings</strong> Barragem Velha</td>
<td>8.8</td>
</tr>
<tr>
<td></td>
<td><strong>Sludge</strong> Barragem Nova</td>
<td>3.2</td>
</tr>
<tr>
<td></td>
<td><strong>Low grade ore</strong> Escomb Sta Barbara</td>
<td>16.2</td>
</tr>
<tr>
<td></td>
<td><strong>Low grade ore</strong> Descarga minério</td>
<td>32.0</td>
</tr>
<tr>
<td></td>
<td><strong>Shaft area</strong> Zona do Poço nº 5</td>
<td>4.5</td>
</tr>
<tr>
<td>GN 1</td>
<td>Old mine area Moreira de Rei</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td>Old mine area Rio de Mel</td>
<td>2.3</td>
</tr>
<tr>
<td>GN 2</td>
<td>Reference Sátão</td>
<td>1.2</td>
</tr>
</tbody>
</table>
REMEDIATION: cover the tailings

- Prevent radon exhalation
- Prevent erosion and environmental dispersion of dust materials
- Prevent removal and use of materials (in building construction, roads, etc.)
- Reduction of external radiation dose

Tailings shall be confined and materials isolated from biosphere
Guidelines
Radiological monitoring for radiation protection in uranium mining

- **Baseline survey:**
  - before the mining of radioactive ore
  - reference for post mining remediation

- **Radiological survey during mine operation:**
  - occupational exposure of miners
  - Control of external radiation (radon, etc) and environmental contamination of waters, soils, forest, etc.

- **Post mine closure:**
  - During remediation works
  - Post remediation surveillance
**Concepts**

- **Surveillance**: inspections to verify the integrity of waste facilities

- **Monitoring**: measurement of radiological, environmental, and other parameters; provide a basis for assessing the effectiveness of waste management practices
Aims of surveillance

- Check integrity and safety of waste facility.
- For example
  - damage by storms
  - human intrusion, use of materials
  - burrowing by animals,
  - plant growth, etc

may lead to release of contaminants
Aims of radiological monitoring

- To demonstrate to regulatory authorities that environmental, radiological, or chemical contamination is not exceeding limits/standards
- To ensure that the critical groups of population are not exposed to enhanced radiation dose from this practice
- To provide information on safety to the authorities and to the public
Monitoring plan

- Based on site specific safety assessment and risk analysis to identify:
  - Critical radionuclides and other chemicals
  - Important pathways contributing to exposure of population
  - Critical components of tailings or mine waste that in failure may result in exposure (weak-links)

- Includes:
  - water quality monitoring (radionuclide concs),
  - atmospheric monitoring (radon, particulates)
  - soil, fauna, flora (food chain)
Groundwater monitoring around a mine site

FIG. 7. Example of groundwater monitoring locations for a tailings area.
Terrestrial ecosystems monitoring

- Ambient gamma dose rate
- *In situ* gamma spectrometry
- Sampling soils, vegetables (cabbage, potatoes, milk,...) for analysis
Aquatic ecosystems monitoring

- Water parameters measurement
- In situ filtration of water samples for radiochemical analyses
- Collection of biota samples for analysis
Atmospheric monitoring

- Measurement of atmospheric radon (outdoors and indoors)
- Sampling aerosol particulates for radioelement analysis
Radionuclide analysis

- Alpha spectrometry
- Gamma spectrometry
- Liquid scintillation
- Alpha-Beta counting
- Analytical Quality Assurance
Dose calculation

- **Taking into account**
  - External radiation
  - Inhalation
  - Ingestion

- **Effective Dose Limit**
  for members of the Public: 1mSv/y
Uranium mining legacy
Uranium mining in Europe

- France
- Germany
- Spain
- Others

Radium production

First medical applications

Radiation protection

First nuclear weapons

Nuclear power plants

Uranium as fissile material

90’s -End of Cold War- closure of U mines in Europe

Environment rehabilitation

1900 1925 1945 1990 2008

YEARS
Legacy of radium and uranium mining in Portugal

Mineralizations of Uranium in the centre-North of Portugal (province/region of Beiras)

- 400 uranium deposits identified
- 60 deposits exploited (open pits or underground)
- Exploitation of radioactive ores 1908-2001
“MinUrar” Project

- Assessment of environmental contamination and effects on population health

- Requested by the Government

**Recommendations**

- To undertake environmental remedial action (site dependent)
- Environmental radiological surveillance of old uranium mining and milling sites
Tailings cover

Aerial view of Urgeiriça (early 2008)

Multi layer cap
Legacy of past uranium mining in France

Many uranium mines sites with:

- A) No significant radiological impact
- B) Some radiological impact
- C) High radiological impact
B) Sites with some radiological impact

Mining waste buried in situ and landscape engineered

Close out and decommissioning

Puy Teigneux: before and after
Legacy of past uranium mining in Germany

- Wismut company (GDR)
- U mining in Saxony 1945-1990
- U ore extracted: 251 000 tonnes
- Cost of site rehabilitation: 6500 MEuros
Schlema mine site, Saxony throughout the years

1960

1993

1996

2000
Post-remediation maintenance and stewardship

- Continuous water treatment
- Sludge-radioactive material
- Long term stewardship
Uranium mining in the Sahara desert, Niger

- Current mining. No legacy.
- Very remote area
- No environmental and radiological impact?
Population

- Near 80,000(!) settled around, attracted by the mines
- Metal scrappers: re use scrap to manufacture commodities

- Water is a very limited resource
- Process and waste water from the mine facilities are treated for use in irrigation (gardens)
Uranium in Sahara

Despite the remote location it is still needed to

- Ensure radiological safety of local population
- Protect groundwater resources
- Avoid dispersion of contaminated dust
Lessons from past U mining

- Post mining restoration generally not planned in advance
- Provision of funds generally not made
- Finally, environmental remediation has been necessary and performed nearly everywhere
- “Reactive” rehabilitation has been costly.
New demands for uranium

Historique de la production et de la consommation d’uranium

<table>
<thead>
<tr>
<th>1940-1969</th>
<th>1970-1984</th>
<th>1985...</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constitution de stocks militaires</td>
<td>Constitution de stocks industriels</td>
<td>Destockage et introduction des matières recyclées (uranium et plutonium)</td>
</tr>
</tbody>
</table>

Milliers de tonnes d’uranium

Besoins des reacteurs

Destockage

Production

Historique prix spot ($ 2007/lbU₃O₈)*

*lb : livre américaine (0,453 kg) ; U₃O₈ : yellow cake.

Source : Nova Energy limited
Future of uranium mining

- Production may increase in the future; regain of interest in nuclear energy
- Some small producers may want to come back into U production
- No future for uranium mining with traditional methods: *a new paradigm is required.*
Environmental restoration as part of uranium production

- Public perception of risks
- Regulators: *Mining licenses* and permits
  - Conformity with new ICRP recommendations and dose limits:
    - Protection of non-human biota
- «Social license»!
  - Trust, acceptable impact, post-extraction rehabilitation
- Costs that must be incorporated in uranium production costs
  - Environment protection
  - Radiological protection of workers and public (1 mSv/y dose limit)
  - Rehabilitation of sites
Thank you for your attention!

THE END