The use and management of NORM residues in processing Bayan Obo ores in China

Wu Qifan, Liu Hua, Ma Chenghui, Zhao Shunping, Zhu Xinhua, Xiong Shengqing, Wang Hongyan

Contents

1. Introduction
2. Mining
3. Processing
4. Management and utilization of Wastes
5. Exposures and environmental impact
6. Summary
# 1. Introduction

Industrial sectors involved NORM or TENORM

- Uranium Overburden and Mine Spoils
- Phosphate Industry Wastes
- Phosphate Fertilizers and Potash
- Coal Ash
- Oil and Gas Production Scale and Sludge
- Waste Water Treatment Sludge
- **Metal Mining and Processing Waste**
- Geothermal Energy Production Waste.
- Paper and pulp Industry
- Scrap Metal Release and Recycling

www.tenorm.com
1. Introduction

Metal and mining industries involved NORM or TENORM

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Bauxite</td>
<td>Lead</td>
<td>Thorium</td>
</tr>
<tr>
<td>Beryllium</td>
<td>Molybdenum</td>
<td>Tin</td>
</tr>
<tr>
<td>Columbium</td>
<td>Nickel</td>
<td>Uranium</td>
</tr>
<tr>
<td>Copper</td>
<td>Rare Earths</td>
<td>Titanium</td>
</tr>
<tr>
<td>Gold</td>
<td>Silver</td>
<td>Zinc</td>
</tr>
<tr>
<td>Iron</td>
<td>Tantalum</td>
<td>Zirconium</td>
</tr>
</tbody>
</table>

www.tenorm.com
1. Introduction

Industry reserve of REO

The world: $112.7 \times 10^6$ t
China: $43 \times 10^6$ t, 38%
1. Introduction

Industry reserve of REO

China: $43 \times 10^6$ t

Bayan Obo deposit: $35 \times 10^6$ t, 81.4%

The rest about $8 \times 10^6$ t
The distribution of Rare Earth deposits in China
1. Introduction

Baiyunebo mines and processing plants

Bayan Obo mine
Main Mine and East Mine
West Mine

Inner Mongolia BaoTou Iron and Steel Plant (Group Ltd.), or BTISP, founded in 1954, 150 km South of Bayan Obo.

Other rare earth plants, after 1974
Bayan Obo mine: 18Km × 2 - 3Km.

- Main Mine and East Mine have reserve of $600 \times 10^6$ t of ores containing about 34% iron, 5% REO and 0.032% ThO$_2$.
- West Mine has $800 \times 10^6$ t of ores with mainly 33.15% irons, but low contents of REs, thorium, phosphorus and fluorine.
The Bayan Obo ores are rich in thorium, so it causes a certain radiological impact on both work places and the environment during mining and processing.
2. Mining

About $276 \times 10^6$ t of ores had been mined by the end of 2006. About $10 \times 10^6$ t/a of ores are recently mined.

a big open pit mine

$1520 \times 1080m^2$ for Main Mine, $1400 \times 1020m^2$ for East Mine
2. Mining

West Mine, a big open pit mine, started in May, 2006.

4,600 m in length
1,000 m to 1,200 m in width.
The present production of ores is expected to be $3 \times 10^6$ t/a,
2. Mining

Large amount of waste rocks is generated in mining, piling up along the dumps on the mining site. About $10 \times 10^6$ t of waste rocks are produced annually.
2. Mining

Total amount of waste rocks is about $560 \times 10^6$ t, piled up in the waste rock dumps.
3. Processing

BTISP produced only iron and steel products at its early stage. It has been producing RE products from RE concentrates in line with iron and steel at the same time since 1974.

The BTISP processes $12 \times 10^6$ t/a of ores from Bayan Obo mine, produces $9 \times 10^6$ t/a of iron and steel and more than $7 \times 10^3$ t/a of oxide equivalent of REO products.
3. Processing

First step

Production of iron and RE concentrates
$4.5 \times 10^6$ t/a and $100 \times 10^3$ t/a respectively
Iron concentrate contains thorium 0.024% to 0.0073%
Rare earth concentrate contains 0.2% thorium
The tailing, $6.55 \times 10^6$ t/a with 0.048% thorium
3. Processing

First step

Tailings, $149 \times 10^6$ t, 2006 occupying an area of 11km$^2$
3. Processing

Production of iron and steel, and REO

- All iron concentrates for the BTISP
- About two thirds of rare earth concentrates for the RE plants in Baotou, the rest for the plants outside Baotou.
• The BTISP recently produces $9 \times 10^6$ t of iron and steel, yielding $3.55 \times 10^6$ t of ferrous slag annually.
3. Processing

Second step

- There are 13 RE plants in Baotou city area.
- Products include RE oxides, RE chlorides, RE carbonates and alloy products.
- $60 \times 10^3 \text{ t/a of RE slag is produced}$ and disposed in Baotou Radioactive Waste Storage Facility.
4. Management and utilization of Wastes

Major flow chart and pollutant production of Bayan Obo ores exploitation.
4. Management and utilization of Wastes

Bayan Obo ores, 0.032% ThO$_2$

Radionuclide concentration in products
The iron and steel products, trace or no RE alloys, 0.04-0.24% Th
RE chlorides, 0.045% Th
RE oxides, 0.0069% Th.

The total amount of thorium content in ores have been redistributed in the slag in solid waste 96-98%
in exhaust gas 0.1-0.5%
in liquid effluent 0.6-2.0%
## 4. Management and utilization of Wastes

The inventory of production of NORM residues (Slags)

<table>
<thead>
<tr>
<th>Slag Type</th>
<th>2006 annual production ($10^4$t)</th>
<th>Stock record (up to 2006) ($10^4$t)</th>
<th>Storage place</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tailing</td>
<td>654.67</td>
<td>14933.7</td>
<td>Baogang tailing pond, Bayan tailing pond</td>
</tr>
<tr>
<td>Alloy</td>
<td>0.58</td>
<td>96.3</td>
<td>Baogang alloy slag dump</td>
</tr>
<tr>
<td>Blast furnace</td>
<td>290</td>
<td>5502.5</td>
<td>Baogang ferrous slag dump</td>
</tr>
<tr>
<td>RE</td>
<td>6.09</td>
<td>26.1</td>
<td>Baotou Radioactive Waste Storage Facility</td>
</tr>
</tbody>
</table>
4. Management and utilization of Wastes

Radiological safety in the exploitation of Bayan Obo ores and utilization of NORM residues is ensured through compliance with the law and national regulations, as well as relevant IAEA standards.
4. Management and utilization of Wastes

- Law of the People's Republic of China on Prevention and control of Radioactive Pollution
- Basic Standards for Protection and Prevention against Ionizing Radiation (GB18871-2002)
- Regulations for radioactive waste management (GB14500 – 2002)
- Requirement of control on radioactive substance for building material product and industrial by-product used in building materials(GB 6763-2000)
- Limit of radionuclides in building materials,
- Standard of limit on radioactive substance for industrial waste slag used in building materials(GB6763-86)
4. Management and utilization of Wastes

4. Management and utilization of Wastes

Baogang tailing pond

Recovery of waste water
4. Management and utilization of Wastes

The gross $\alpha$ activity concentration of acidic process slag is $8 \times 10^4$-$2 \times 10^5$Bq/kg, exceeds the activity level of low level radioactive solid waste.
4. Management and utilization of Wastes

Uses of waste rocks → road construction and the bank of tailing pond

Recovery of waste water → $64.57 \times 10^6$ t/a

Recovery of acid → 45,000 t/a of sulphuric acid

The uses of blast furnace slag

→ Recovery of waste iron

→ as materials to make cement, bricks and other building products
4. Management and utilization of Wastes

- The uses of blast furnace slag
- Recovery of iron
- brickyard
4. Management and utilization of Wastes

• The BTISP produced blast furnace slag, 3,550,000 t/a
• Use of blast furnace, about 1,450,000 t/a
• The consumption of the slag is nearly a half based on the recent utilization rate.
• The usual way to produce construction materials from blast furnace slag is to mix blast furnace slag and the low radioactive material such as fly ash together. The products meet the requirements of radioactive level for construction materials.
4. Management and utilization of Wastes

Major enterprises and their products used ferrous slag in 2007

<table>
<thead>
<tr>
<th>Factories</th>
<th>Major products</th>
<th>Production</th>
<th>Ra-226</th>
<th>Th-232</th>
<th>K-40</th>
</tr>
</thead>
<tbody>
<tr>
<td>A brick factory</td>
<td>paving bricks</td>
<td>52,208 m², house bricks 32,144 m³</td>
<td>51</td>
<td>212</td>
<td>123</td>
</tr>
<tr>
<td></td>
<td>house bricks</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cement factory 1</td>
<td>Cement</td>
<td>6×10⁵ t</td>
<td>83.6</td>
<td>330.9</td>
<td>429.2</td>
</tr>
<tr>
<td>Cement factory 2</td>
<td>425# cement</td>
<td>3.78×10⁵ t</td>
<td>24.6</td>
<td>240.1</td>
<td>371.9</td>
</tr>
</tbody>
</table>
5. Exposures and environmental impact
5. Exposures and environmental impact

(1) Gamma radiation levels

The regions covering about 2060km² has been flown in 2006, by the airborne gamma spectrometry for radioactivity mapping.

The follow-up ground measurements to verify the elevated areas were carried out.

Baiyun: 23Km × 28Km
Baotou: 42.5Km × 30 Km
5. Exposures and environmental impact

Airborne gamma spectrometry

The AGS system was installed in fixing wings aircraft, with large volume (32L) sodium iodide (NaI(Tl)) detector.

GR-820

Nal (TI) detector
5. Exposures and environmental impact

Follow up ground work

In Situ HPGe Gamma Spectrometer

The CGS system was installed in jeep, with large volume (4L), GR460, NaI(TI) detector.
5. Exposures and environmental impact

Dose meter

$^{222}\text{Rn}/\; ^{220}\text{Rn}$ and $^{220}\text{Rn}$ progeny
CR-39 detector
5. Exposures and environmental impact

Gamma radiation levels in Baiyunebo

Gamma radiation levels in Baotou
5. Exposures and environmental impact
Bayan Obo
- BG: 85nGy/h, HBG: 200—800nGy/h and about 55.4 Km²
- Mining sites: 600 to 2000nGy/h
- Dumping sites: 400 to 800nGy/h
- The contaminated soil area:
  - 100-150nGy/h,
  - 80-120Bq/kg in the upper layer of 10 -20cm.

Baotou
- BG: 65nGy/h, HBG: 500-1,000nGy/h and about 7 km²
- Tailing pond: 650-1200 nGy/ h and 11 Km².
- Ferrous slag dump: 500-1200 nGy/ h and 0.8Km².
- The contaminated soil area:
  - 85-150nGy/h,
  - 80-200Bq/kg in the upper layer of 10 -20cm.
  - background, 50Bq/Kg.
- 32 hot spots: 120-1200nGy/h
hot spots: 120-1200 nGy/h

abandoned rare earth plants
hot spots: 120-1200nGy/h

The plant is closed, but rare earth slag left
5. Exposures and environmental impact

(2) Exposures (Bayan obo)

- Most of workers receive 0.24-0.7 mSv/a of additional external exposures
- But some workers may receive more than 1.0 mSv/a

Public in the Bayan Obo city area
The additional external exposure is 0.044 mSv/a
5. Exposures and environmental impact

(2) exposures (Baotou)

• (a) Occupational exposures
  The additional external exposures for workers are in range of 0.3-0.6 mSv/a

• (b) Public exposures
  The additional external exposure is 0.043 mSv/a for members of the public living in the soil contaminated area.
  The indoor effective dose for the buildings containing no slag is 1.86 mSv/a in Baotou City area (similar to other places in China), but the dose becomes higher than 2.0 mSv/a for most of the buildings made of slag bricks.
6. Summary

(1) Exposures

- Additional exposure received by members of the public is not significant
- but for some workers, probably exceeds 1.0 mSv/a.
6. Summary

(2) Use and management of Norm Residues

• Tailings and RE slag are stored as mineral reserves.

• larger amount of slag was used for building material that meet the radiation safety requirements.
6. Summary

（3）Problems and Measures

- Large amount of wastes (iron slag) is big problem, needed to reduce
- But when wastes are used, radioactive problems occur.
  - A typical example of spread of NORM is the building bricks made of the residues.
  - A criterion should be set to confine the uses of NORM residues to banned, conditional and unconditional uses in terms of activity concentration of NORM residues.
  - The uses of these construction materials should be restricted.
6. Summary

(3) Problems and Measures (cont.)
• some plants are closed, but residues and wastes do not return to stack. These plants need to be decommissioned
6. Summary

(3) Problems and Measures (cont.)

- Remediation project concerning contaminated soils has been discussed and taken into account.
- A campaign for survey on pollution of radioactive sources has started nationwide since 2007.
ACKNOWLEDGEMENTS

• The NORM6 national organizing committee and IAEA
• Department of Nuclear Safety Management of Ministry of Environment Protection of China
• China Aero Geophysical Survey & Remote Sensing Center for Land and Resources
• Mr. Pan Ziqiang
• Dr. Virginia Koukouliou
• Dr. Denis Wymer
• Professor Ahmed FAHLI
<table>
<thead>
<tr>
<th>Name</th>
<th>Department and Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mr. Pan Su</td>
<td>Dept. of Nuclear Safety Management of MEP</td>
</tr>
<tr>
<td>Mr. Feng Youcai</td>
<td>Dept. of Nuclear Safety Management of MEP</td>
</tr>
<tr>
<td>Mr. Li Rujun</td>
<td>Dept. of Nuclear Safety Management of MEP</td>
</tr>
<tr>
<td>Mr. Cheng Jianping</td>
<td>Dept. of Engineering Physics of Tsinghua University</td>
</tr>
<tr>
<td>Mr. Qin Zhangjian</td>
<td>Dept. of Engineering Physics of Tsinghua University</td>
</tr>
<tr>
<td>Mr. Jin Ge</td>
<td>Dept. of Engineering Physics of Tsinghua University</td>
</tr>
<tr>
<td>Mr. Yang Bin</td>
<td>Zhejiang Province Environmental Radiation Monitoring Center</td>
</tr>
<tr>
<td>Mr. Ma Yongfu</td>
<td>Zhejiang Province Environmental Radiation Monitoring Center</td>
</tr>
<tr>
<td>Mr. Yang Weigeng</td>
<td>Zhejiang Province Environmental Radiation Monitoring Center</td>
</tr>
<tr>
<td>Song Jianfeng</td>
<td>Zhejiang Province Environmental Radiation Monitoring Center</td>
</tr>
<tr>
<td>Xiang Yuanyi</td>
<td>Zhejiang Province Environmental Radiation Monitoring Center</td>
</tr>
<tr>
<td>Zheng Guodong</td>
<td>Zhejiang Province Environmental Radiation Monitoring Center</td>
</tr>
<tr>
<td>Mr. Sui Wenli</td>
<td>Inner Mongolia Radioactive Environment Management Institute</td>
</tr>
<tr>
<td>Ms. Liu Guifang</td>
<td>Inner Mongolia Radioactive Environment Management Institute</td>
</tr>
<tr>
<td>Ms. Wang Xiaoqing</td>
<td>Inner Mongolia Radioactive Environment Management Institute</td>
</tr>
<tr>
<td>and Mr. Li Xiansheng</td>
<td>Inner Mongolia Radioactive Environment Management Institute</td>
</tr>
<tr>
<td>Mr. Luo Jianjun</td>
<td>Nuclear and Radiation Safety Center of MEP</td>
</tr>
<tr>
<td>Mr. Liu Xinhua</td>
<td>Nuclear and Radiation Safety Center of MEP</td>
</tr>
</tbody>
</table>

OTHER CONTRIBUTORS OF THE RESEARCH PROGRAMME
Thank you for your attention!