Management of NORM - A Canadian perspective

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DISCLAIMER

- Views and opinions are mine and I am not representing ICRP Committee 4 nor my employer Cameco Corporation.
Outline

- Introduction
- Industries impacted by Naturally Occurring Radioactive Materials (NORM)
- Canadian Regulatory Approach
- Practical Implementation Issues
Introduction

- Naturally Occurring Radioactive Material
  - Present in varying concentrations in most materials
- Primordial radionuclides
  - Uranium 238 (and decay series)
  - Thorium 232 (and decay series)
  - Potassium 40
  - Very low concentrations of others (e.g., U 235 decay series)
Introduction

- Concentration of NORM in most substances low
- Human activities can lead to higher concentrations
- In some situations necessitates the need safety measures
- Can occur at different stages
  - Handling
  - Processing
  - Transport
  - Disposal
Introduction

From Wymer 2008. NORM V IAEA

[Diagram showing activity concentration of different materials and data from UNSCEAR 2000]

Non-optimum use of regulatory resources
Optimum use of regulatory resources

Uranium ores, U-238
Monazite, Th-232
Pyrochlore, Th-232
Zircon, U-238
Ilmenite, Th-232
Rutile, U-238
Phosphates, U-238
Bauxite
Other metal ores, U-238 or Th-232
Soil, U-238
Soil, Ra-226
Soil, Th-232

Activity concentration (Bq/g)

0.001 0.01 0.1 1 10 100 1000 10000

Data from UNSCEAR 2000

From Wymer 2008. NORM V IAEA
Industries Impacted by NORM

- **Mineral Extraction and Processing**
  - NORM may be released or concentrated in a process stream during the processing of ore
  - K-40, U-238, and Th-232 decay series in variety of ore formations
Industries Impacted by NORM

- **Oil and Gas Production**
  - trace quantities of NORM may be found in hydrocarbon bearing geological formations
  - Oil production - Ra-226 can precipitate on process equipment
  - Gas production - Rn-222 in natural gas and can Pb-210 accumulate inside gas processing equipment
Industries Impacted by NORM

- Water Treatment Facilities
  - Water (fresh or waste) treated through sorptive media or ion-exchange resins to remove impurities may concentrate NORM and may release radon
  - Fish hatcheries
Industries Impacted by NORM

- Tunnelling and Underground Workings
  - Release of radon in underground mines
Industries Impacted by NORM

- Thermal-Electric Production and Forest Products
  - Mineral ashes from combustion may concentrate NORM present in coal and plants
Industries Impacted by NORM

- Metal recycling
  - NORM contaminated can be redistributed
Canadian Regulatory Approach

- Canadian federal regulator (Canadian Nuclear Safety Commission - CNSC) mandate covers nuclear fuel cycle from uranium mining to nuclear power plants and transport of radioactive materials
- Most other industries impacted by NORM are under provincial legislation
- Canadian Guidelines for the Management of Naturally Occurring Radioactive Materials (NORM) 2011
  - Jointly developed by federal, provincial, and territorial regulators
  - High-level guidance and basis for specific regulations
Canadian Guidelines for the Management of NORM

- Incorporates guidance from International Commission on Radiological Protection (ICRP) and CNSC regulations
  - ICRP principles of Justification, Optimization, Limitation
  - The emphasis is on optimization and limitation for occupational (and public) exposures
  - Recommended occupational dose limit for NORM workers
    - 50 mSv/y, 100 mSv/5y - practical limit of 20 mSv/y
    - Only applies to workers who are exposed to NORM as part of routine duties
    - Incidentally exposed workers treated as member of public with 1 mSv/y limit
**NORM Program Classifications**

- A dose constraint of 0.3 mSv/y is recommended
- If < 0.3 mSv/y no further actions required
- If > 0.3 mSv/y develop NORM management program
- If workers doses > 1 mSv/y need Dose Management Program
  - Consider PPE, training
  - Estimate doses to workers
- If worker doses > 5 mSv/y need formal Radiation Protection Management Program
  - PPE, training, procedures
  - Individual dosimetry
NORM Material Management

- NORM Derived Release Limits (DRLs)
  - 0.3 mSv/y used as dose constraint in calculation
  - Used to set criteria for unconditional release
  - Still may need to consider non-radiological properties and other criteria
  - Distinction between DIFFUSE NORM and DISCRETE NORM
    - Diffuse NORM - high volume, low radioactive concentration, uniformly distributed throughout the material
    - Discrete NORM - exceed concentration limit for diffuse NORM
  - DRL’s calculated on pathways analysis
## Unconditional Derived Release Limits - Diffuse NORM Sources

<table>
<thead>
<tr>
<th>NORM Radionuclide</th>
<th>Derived Release Limit(^{(b)})</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Aqueous(^{(b)}) (Bq/L)</td>
<td>Solid (Bq/kg)</td>
<td>Air (Bq/m(^3))</td>
</tr>
<tr>
<td>Uranium-238 Series (all progeny)</td>
<td>1</td>
<td>300</td>
<td>0.003</td>
</tr>
<tr>
<td>Uranium-238 (U-238, Th-234, Pa-234m, U-234)</td>
<td>10</td>
<td>10,000</td>
<td>0.05</td>
</tr>
<tr>
<td>Thorium-230</td>
<td>5</td>
<td>10,000</td>
<td>0.01</td>
</tr>
<tr>
<td>Radium-226 (in equilibrium with its progeny)</td>
<td>5</td>
<td>300</td>
<td>0.05</td>
</tr>
<tr>
<td>Lead-210 (in equilibrium with bismuth-210 and polonium-210)</td>
<td>1</td>
<td>300</td>
<td>0.05</td>
</tr>
<tr>
<td>Thorium-232 Series (all progeny)</td>
<td>1</td>
<td>300</td>
<td>0.002</td>
</tr>
<tr>
<td>Thorium-232</td>
<td>1</td>
<td>10,000</td>
<td>0.006</td>
</tr>
<tr>
<td>Radium-228 (in equilibrium with Ac-228)</td>
<td>5</td>
<td>300</td>
<td>0.005</td>
</tr>
<tr>
<td>Thorium-228 (in equilibrium with all its progeny)</td>
<td>1</td>
<td>300</td>
<td>0.003</td>
</tr>
<tr>
<td>Potassium-40</td>
<td>n/a(^{(c)})</td>
<td>17,000(^{(c)})</td>
<td>n/a</td>
</tr>
</tbody>
</table>
### Unconditional Derived Release Limits

<table>
<thead>
<tr>
<th>NORM Radionuclide</th>
<th>Unconditional Derived Release Limit (^{(a)}) (Bq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uranium Ore (in equilibrium with all progeny)</td>
<td>1,000</td>
</tr>
<tr>
<td>Uranium-238 (partitioned) (in equilibrium with thorium-234 and protactinium-234)</td>
<td>10,000</td>
</tr>
<tr>
<td>Thorium-230 (no progeny)</td>
<td>10,000</td>
</tr>
<tr>
<td>Radium-226 (in equilibrium with its progeny)</td>
<td>10,000</td>
</tr>
<tr>
<td>Lead-210 (in equilibrium with bismuth-210 and polonium-210)</td>
<td>10,000</td>
</tr>
<tr>
<td>Thorium-232 (in equilibrium with all progeny)</td>
<td>1,000</td>
</tr>
<tr>
<td>Radium-228 (in equilibrium with actinium-228)</td>
<td>100,000</td>
</tr>
<tr>
<td>Thorium-228 (in equilibrium with its short-lived progeny)</td>
<td>10,000</td>
</tr>
<tr>
<td>Potassium-40</td>
<td>1,000,000</td>
</tr>
</tbody>
</table>
Discrete NORM Sources

- Discrete NORM sources must also meet surface contamination limits
  - 0.5 µSv/h at 50 cm
  - 1 Bq/cm² averaged over 100 cm²
  - Applies to fixed surface contamination; loose surface contamination completely removed
  - Recommended to use thin-window beta/gamma detector
Practical Implications - Rn in Workplaces

- Radon released from water impacting work environment in fish hatcheries
Practical Implications - Rn in Workplaces

- Application of Canadian NORM Guideline - province of Ontario

<table>
<thead>
<tr>
<th>Average annual concentration of radon [Bq/m³]</th>
<th>NORM program classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>800 – 3,000</td>
<td>Radiation Protection Management</td>
</tr>
<tr>
<td>200 – 800</td>
<td>NORM Management</td>
</tr>
<tr>
<td>Background – less than 200</td>
<td>Unrestricted</td>
</tr>
</tbody>
</table>

### Practical Implications - Rn in Workplaces

#### Radon in Cody Caves Form

<table>
<thead>
<tr>
<th>Monitor Number</th>
<th>Start Date MM-DD-YY</th>
<th>End Date MM-DD-YY</th>
<th>Location</th>
<th>Site Identification</th>
<th>Radon in pCi/l</th>
<th>Radon in Bq/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>4655692</td>
<td>9-19-06</td>
<td>10-26-06</td>
<td>Entrance</td>
<td>Cody C.1</td>
<td>86.1</td>
<td>3185.7</td>
</tr>
<tr>
<td>4655654</td>
<td>9-19-06</td>
<td>10-26-06</td>
<td>Entrance</td>
<td>Cody C.1</td>
<td>83.9</td>
<td>3104.3</td>
</tr>
<tr>
<td>4655664</td>
<td>9-19-06</td>
<td>10-26-06</td>
<td>Porcupine Passage</td>
<td>Cody C.2</td>
<td>85.2</td>
<td>3152.4</td>
</tr>
<tr>
<td>4655608</td>
<td>9-19-06</td>
<td>10-26-06</td>
<td>Porcupine Passage</td>
<td>Cody C.2</td>
<td>71.0</td>
<td>2775.0</td>
</tr>
<tr>
<td>4655697</td>
<td>9-19-06</td>
<td>10-26-06</td>
<td>Twilight A</td>
<td>Cody C.3</td>
<td>81.9</td>
<td>3104.3</td>
</tr>
<tr>
<td>4655683</td>
<td>9-19-06</td>
<td>10-26-06</td>
<td>Twilight A</td>
<td>Cody C.3</td>
<td>82.8</td>
<td>3063.6</td>
</tr>
<tr>
<td>4655651</td>
<td>9-19-06</td>
<td>10-26-06</td>
<td>Twilight B</td>
<td>Cody C.4</td>
<td>83.3</td>
<td>3082.1</td>
</tr>
<tr>
<td>4655710</td>
<td>9-19-06</td>
<td>10-26-06</td>
<td>Upper Rm</td>
<td>Cody C.5</td>
<td>91.8</td>
<td>3396.6</td>
</tr>
<tr>
<td>4655642</td>
<td>9-19-06</td>
<td>10-26-06</td>
<td>Upper Rm</td>
<td>Cody C.5</td>
<td>90.1</td>
<td>3348.5</td>
</tr>
<tr>
<td>4655652</td>
<td>9-19-06</td>
<td>10-26-06</td>
<td>Balcony Rm</td>
<td>Cody C.6</td>
<td>102.8</td>
<td>3803.6</td>
</tr>
<tr>
<td>4655633</td>
<td>9-19-06</td>
<td>10-26-06</td>
<td>Balcony Rm</td>
<td>Cody C.6</td>
<td>94.5</td>
<td>3496.5</td>
</tr>
</tbody>
</table>
Practical Implementation Issues

- Coal ash - about 10% by weight and radionuclides can be concentrated by a factor of ~10x
- Fly ash long-term use and disposal

From US Geological Survey Fact Sheet FS-163-97
Oil and gas industries have to deal with NORM

Occupational issues
- Radon exposures
- Inhalation hazard from long-lived alpha activity
- External gamma radiation
Practical Implementation Issues

- Condensate $^{222}\text{Rn}$ and particulate scale
- Particulate scale and $^{222}\text{Rn}$
- Oil
- Gas
- Water

- $^{222}\text{Rn}$, $^{210}\text{Pb}$, $^{210}\text{Po}$ plates tubular
- Ra isotopes precipitate as mineral scale
- $^{238}\text{U}$, $^{232}\text{Th}$
- $^{222}\text{Rn}$ migrates with gas
- $^{226}\text{Ra}$, $^{228}\text{Ra}$, $^{224}\text{Ra}$, $^{222}\text{Rn}$
  Mobilise with hydrocarbons and produced water
## Practical Implementation Issues

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Natural gas Bq/m³</th>
<th>Produced water Bq/L</th>
<th>Hard scale Bq/kg</th>
<th>Sludge Bq/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>U-238</td>
<td>trace</td>
<td>1 - 500</td>
<td>5 - 10</td>
<td></td>
</tr>
<tr>
<td>Ra-226</td>
<td>0.002 - 1200</td>
<td>100 - 15 million</td>
<td>50 - 800,000</td>
<td></td>
</tr>
<tr>
<td>Po-210</td>
<td>0.002 - 0.08</td>
<td>20 - 1500</td>
<td>4 - 160,000</td>
<td></td>
</tr>
<tr>
<td>Pb-210</td>
<td>0.005 - 0.02</td>
<td>0.05 - 190</td>
<td>20 - 75,000</td>
<td>10 - 1.3 million</td>
</tr>
<tr>
<td>Rn-222</td>
<td>5 - 200,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Th-232</td>
<td>trace</td>
<td>1 - 2</td>
<td>2 - 10</td>
<td></td>
</tr>
<tr>
<td>Ra-228</td>
<td>0.3 - 180</td>
<td>50 - 2.8 million</td>
<td>500 - 50,000</td>
<td></td>
</tr>
<tr>
<td>Ra-224</td>
<td>0.05 - 40</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: IAEA 2003, Safety Report Series 34.
Practical Implementation Issues
Practical Implementation Issues

- Occupational safety measures
  - PPE
  - contamination control
  - work practices to minimize generation of airborne dust
  - Signage for radiation areas
- Radiation surveys
  - Process area and equipment
  - Po-21, Bi-210, Pb-210 in pipes have no discernable gamma signal
  - Scrap metal being shipped off site
  - Airborne radioactivity sampling
Practical Implementation Issues

- Transport of NORM governed by CNSC (federal) Transport and Packaging of Radioactive Materials Regulations and Transportation of Dangerous Goods Regulations
  - NORM contaminated equipment
Practical Implementation Issues

- NORM Waste Disposal
  - Underground salt cavern
  - 300 Bq/g per radionuclide
- Accepts other types of waste
  - Solvents, greases, lubricants, paint wastes, metal contaminated sludges, non-chlorinated organic wastes
Practical Implementation Issues

- Landfill Disposal of NORM
  - 70 Bq/g (except 55 Bq/g for Ra-226, 2 Bq/g for U-Nat, Th-232 - 6 Bq/g)
  - Some hazardous substances also accepted
Conclusions

- NORM issues impact many industries
- Doses to workers and public are generally low
- Standard occupational radiation protection practices work well to control occupational exposures
- Disposal of NORM aligned with other hazardous wastes
- Growing awareness of NORM issues
Questions???
Primary References

- Suncor Energy Naturally Occurring Radioactive Material Standard. Revision date 2017/07/31