Management of Carbon-14 Emissions and Environmental Impacts at Ontario Power Generation Nuclear

RETS/REMP Workshop
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Tho-Dien Le
Presentation Outlines

- Overview of OPG Nuclear Power Plants
- Overview of CANDU reactor system
- Production of Carbon-14 in CANDU system
- Carbon 14 emission sources
- Emissions monitoring of Carbon-14
- Environmental monitoring of Carbon-14 and public dose contribution
- Regulatory Requirements & Public Communications on Carbon-14
Darlington Nuclear

- OPG’s newest CANDU nuclear generating station
- 4 CANDU reactors with total output of 3,500MW
- Located on Lake Ontario 70km east of Toronto
- Areas around Darlington site are mainly rural and farm lands with some industrial/commercial areas.
- Closest urban residential locations are more than 3km from the site
Pickering Nuclear

- Two Nuclear Stations: Pickering A (2 units) and B (4 units)
  - Total output of 3,200MW (6x540 MWe)
- Located on Lake Ontario 30 km east of Toronto
- Areas around site are mainly urban residential and industrial/commercial
- Closest farm lands are more than 6 km from the site
- Nearest resident is 1km from the site
CANDU Reactor Overview

- **Calandria:**
  - Horizontal stainless steel vessel
  - ~80,000 US gal of heavy water to moderate neutrons
  - 400 ft³ helium cover gas – Pickering A has 7000 ft³

- **Fuels:**
  - Natural uranium fuel bundles fit inside 400 - 500 zirconium alloy pressure tubes
  - Zirconium alloy Calandria tubes cover pressure tubes

- **Annulus gas:**
  - CO₂ gas provides insulation between the Pressure tubes and Calandria tubes
  - Moisture monitoring to detect leak

- **Heat Transport:**
  - Pressurized heavy water flows through each pressure tube transferring fission heat to boilers
C-14 Production

- Carbon-14 ($^{14}C$) is produced in the CANDU reactor by neutron activation of:
  - $^{17}O$ ~90% of production
  - $^{14}N$ ~8%
  - $^{13}C$ <1%

- $^{14}C$ production occurs in high neutron flux regions of the reactor:
  - Moderator ~90% of production
  - Heat Transport (i.e. RCS) ~2%
  - Annulus Gas ~0.2%
  - Fuel ~8%
C-14 Production and Release Rates in Various Reactor Types\(^{(1)}\)\(^{(2)}\)

<table>
<thead>
<tr>
<th>Reactor Type</th>
<th>Production Rate (Ci/GWe/Yr)</th>
<th>Release Rate (Ci/GWe/Yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fuel</td>
<td>Moderator &amp; PHT</td>
</tr>
<tr>
<td>LWR-PWR</td>
<td>10.8</td>
<td>8.1</td>
</tr>
<tr>
<td>LWR-BWR</td>
<td>16.2</td>
<td>10.8</td>
</tr>
<tr>
<td>HWR</td>
<td>16.2</td>
<td>675.7</td>
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<tr>
<td>GCR-MGR</td>
<td>81</td>
<td>189.2</td>
</tr>
<tr>
<td>GCR-AGR</td>
<td>27</td>
<td>270</td>
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<tr>
<td>GCR-HTGR</td>
<td>5.4</td>
<td>75.7</td>
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</tbody>
</table>


\(^{(2)}\) ACRP-14: management of Carbon 14 in Canadian Nuclear Facilities- Advisory Committee on Radiological protection (1985)
Sources of C-14 Emissions

- Moderator system is major contributor to emissions
- Production rate in moderator is ~1 - 2 Ci/day (540 MW – 875 MW)
- ~96% of $^{14}$C is retained on moderator IX resin
- $^{14}$C emitted via:
  - Moderator cover gas fugitive helium losses (~4% of moderator total)
  - Spent resin storage tanks cover gas air exchange (~0.1 Ci/wk)
  - Liquid Radioactive Waste discharges (<0.5 Ci/a)
Activities Impacting C-14 Emissions

-Leaks and purging of the Moderator Cover Gas
-Operating Moderator IX columns beyond its useful life
-Slurry activities (agitating spent resin in Spent Resin Storage Tanks with potentially acidic slurry water)
-Spent resin transfer to waste storage
Initiatives to Minimize $^{14}$C Emissions

- Limit service life, about 2000 hours, of the moderator IX columns before onset of oxidation-induced loss of capacity
- Impose a stringent outlet conductivity limits (0.05mS/m) on moderator IX columns during operation.
- Prevent on-power moderator IX columns from being subjected to acidic conditions (i.e. poison pulls using only fresh IX).
- Use scrubber during moderator drain/refill activities and transfer of spent resin to containers for shipment to central storage facility
- Reduce inventory of spent resin at stations by sending to waste storage
C-14 Emissions Monitoring

- Monitoring $^{14}$C emissions since 1985 at Pickering; 2000 at Darlington:
  - Reactor Building Ventilation
  - Tritium Removal Facility Ventilation
  - Radioactive Liquid Waste discharges

Airborne:

- Continuously sampling airborne effluents using caustic bubblers and analyze caustic solution weekly using liquid scintillation
- Two sample streams: one heated and one un-heated for determination of total $^{14}$C and $^{14}$CO₂
- Organic $^{14}$C content is very small
C-14 Emissions Monitoring

Waterborne:

- Monthly composite sample of C-14 from all Radioactive Liquid Waste discharges is collected and analyzed

<table>
<thead>
<tr>
<th>Effluents</th>
<th>Pickering</th>
<th>Darlington</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airborne</td>
<td>84</td>
<td>35</td>
</tr>
<tr>
<td>Waterborne</td>
<td>0.01</td>
<td>0.1</td>
</tr>
</tbody>
</table>
Trends of C-14 Emissions from DN & PN Sites

DN Site

PN Site

Year

Bq

0.0E+00
0.5E+12
1.0E+13
1.5E+13
2.0E+13
01 02 03 04 05 06 07 08 09 10

Year

Bq

0.0E+00
0.5E+12
1.0E+13
1.5E+13
2.0E+13
01 02 03 04 05 06 07 08 09 10
C-14 Environmental Monitoring

- Environmental monitoring of $^{14}$C at PN since 1982 and at DN since 1986
- Monitoring $^{14}$C in various environmental media to estimate radiation impact of $^{14}$C to the public
- Periodic site specific survey of communities within 5 km radius of each station
- Categorize public into groups in accordance with their habits, diets and life styles, e.g. urban residents, dairy farms, farms, industrial groups, to establish Critical Groups
- Environmental sampling at Critical Group locations and at background locations
C-14 Environmental Monitoring

- Transfer pathways of $^{14}$C to human dictate $^{14}$C sample media:
  - Inhalation: air
  - Absorption: air, water, soil and sediment
  - Ingestion: water, soil, sediment, aquatic plants & animals and terrestrial plants and animals

- Environmental samples obtained from volunteering participants and purchased from local producers

Passive Sampler for C-14 in Air Monitoring
## C-14 Sampling Locations, Media and Frequency

<table>
<thead>
<tr>
<th>Media</th>
<th>Sampling Location</th>
<th>Sample Frequency</th>
<th>Analysis Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>• Boundary</td>
<td>Continuously</td>
<td>Quarterly</td>
</tr>
<tr>
<td></td>
<td>• Critical Group</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Background</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Milk</td>
<td>• Critical Group</td>
<td>Weekly</td>
<td>Monthly</td>
</tr>
<tr>
<td>Milk</td>
<td>• Background</td>
<td>Quarterly</td>
<td>Quarterly</td>
</tr>
<tr>
<td>Fish</td>
<td>• Boundary</td>
<td>Semiannually</td>
<td>Annually</td>
</tr>
<tr>
<td></td>
<td>• Background</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sediment</td>
<td>• Boundary</td>
<td>Every 5 years</td>
<td>Every 5 years</td>
</tr>
<tr>
<td></td>
<td>• Background</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fruit &amp; Vegetable</td>
<td>• Critical Group</td>
<td>Annually</td>
<td>Annually</td>
</tr>
<tr>
<td></td>
<td>• Background</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PN Sewage Effluent</td>
<td>• Boundary</td>
<td>Weekly</td>
<td>Quarterly</td>
</tr>
</tbody>
</table>
Darlington Critical Groups and Sample Locations
Pickering Critical Groups and Sample Locations

Figure C2 Pickering Nuclear Site Critical Groups and Environmental Monitoring Locations

Legend:
- WADE
- MUD
- ROCK FORMATIONS
- WELL WATER
- LAKE WATER
- WATERS SUPPLY PLANT
- PEAKED REGIONS
- POTENTIAL CRITICAL GROUP
- TRANSMISSION LINES
- RAILROAD LINES
- URBAN AREAS
- Large industrial commercial buildings

NOTES:
- 1. Map extent: latitude 43° 59' 00" W. longitude 79° 16' 00" W.
- 2. Data as of February 2011
- 3. Map legend and symbols solely for reference purposes
- 4. Map scale: 1:30,000 (1 inch = 3000 feet)
- 5. Map created by Ontario Power Generation
- 6. Map data provided by Environment Canada and Natural Resources Canada
- 7. Map updated in 2011
- 8. Map contains information from the Federal Government of Canada
C-14 Public Dose Impact

- Estimation of $^{14}$C dose to public:
  - Canadian Standard CSA N288.1 and IMPACT Software
  - Environmental sample results and
  - Actual survey data of affected groups (actual critical groups not hypothetical ones)
- 2010 site official public doses for Pickering and Darlington stations were 1.0 $\mu$Sv and 0.6 $\mu$Sv (0.1 mrem and 0.06 mrem)
- Dose contribution of C-14 to the overall reported public doses were below 2% for Pickering and 80% for Darlington
- Difference due to “residential” versus “agricultural” nearest neighbours
- Most affected group by C-14 at Darlington and Pickering was an infant at dairy farm
Canadian Regulatory Requirements on Carbon-14

- Establish Derived Release Limit and Action level for C-14
- Report C-14 emissions every quarter
- Report annual inventory of C-14 held at nuclear power generation and waste management sites
- Report C-14 measurements in the environment and its dose impact to the public annually
C-14 Communications

- $^{14}$C emissions reported quarterly to the Regulator (CNSC)
- $^{14}$C dose reported annually to the Regulator (CNSC) via the Corporate REMP Report
- Annual REMP reports are available to the public via OPG public web site (www.opg.com)
- Annual appreciation letters and gifts to local residents who participate in the REMP sampling program and share $^{14}$C results in their environmental samples
- Monitoring results and dose impact of $^{14}$C are presented to the local communities annually:
  - Community Advisory Council at Pickering site
  - Site Planning Committee at Darlington site
  - Durham Nuclear Health Committee
Summary

- OPG has monitored $^{14}$C emissions and $^{14}$C in the environment since the 1980s
- Less than 10% $^{14}$C produced is emitted to the environment
- Levels of $^{14}$C emissions are highly dependent on conductivity of the Moderator purification resin (IX columns) and stability of spent resin in the storage tanks
- Majority of $^{14}$C dose to the public comes from the consumption of terrestrial plants
- Dose contribution of $^{14}$C to the overall reported public doses were 2% for Pickering and 80% for Darlington
- Routine communications with the public through community advisory committee and regional Nuclear Health Committee help maintaining solid relationship with communities
Questions?
Required Resources for C-14 Monitoring & Reporting

- **Emission Monitoring Costs ($CAD):**
  - Cost of sampler (incl. installation): $130,000 each
  - Maintenance, sampling, analyzing and reporting cost: $100,000/yr (4 weekly airborne samples & 1 monthly waterborne sample)

- **Environmental Monitoring Costs ($CAD):**
  - Cost of $^{14}$C in air Sampler: $350.00 each
  - Sampling, analyzing and reporting: $30,000/Yr (for 110 samples)
Trends of C-14 in DN and PN Environmental Media

Carbon 14 in Air at Station boundary

Carbon 14 in Milk
Trends of C-14 in DN and PN Environmental Media

Carbon 14 in Fish

Carbon 14 in Vegetation