Small Modular reactors (SMRs) in remote areas: the needs for chemistry

By

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SMRs: the needs for chemistry

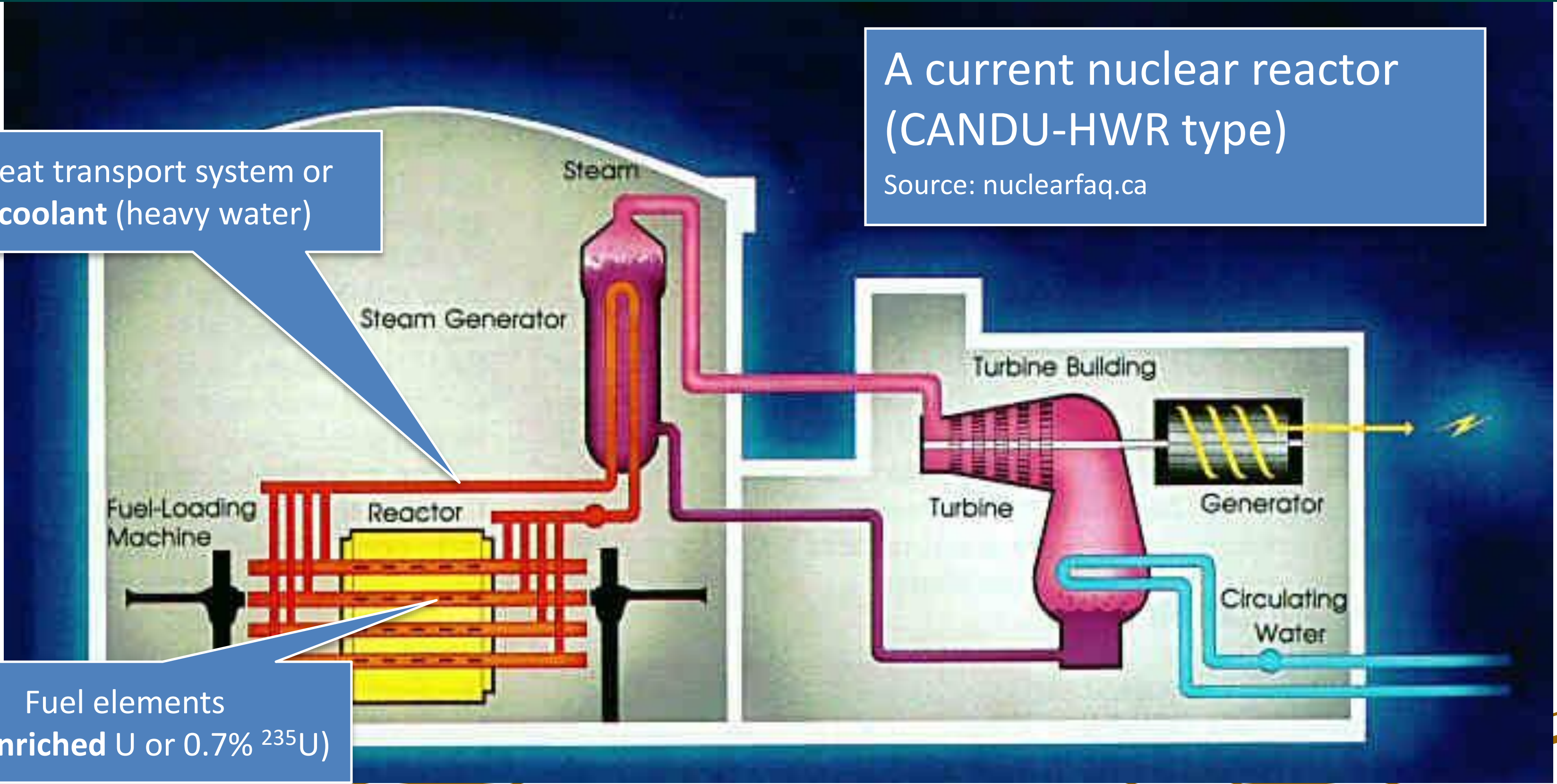
- What is an SMR?
- The needs for SMRs
- The challenges and innovation for chemists
- Case study
- Conclusions

What is an SMR?

A current nuclear reactor (CANDU-HWR type)

Source: nuclearfaq.ca

Heat transport system or **coolant** (heavy water)



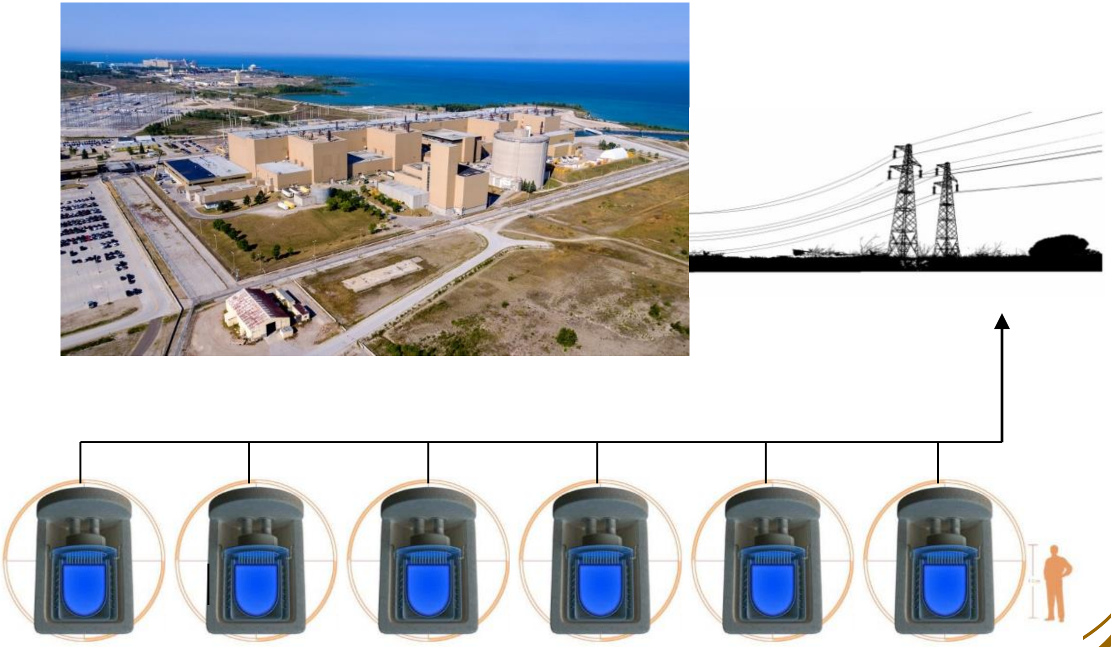
Fuel elements (**un-enriched** U or 0.7% ^{235}U)

What is an SMR?

The World Nuclear Association (WNA) and International Atomic Energy Agency (IAEA) define:

- **Large**: > 700 MWe
- **Medium**: 300-700 MWe
- **Small**: 150-300 MWe
- **Very small**: <150 MWe

(typically: 3 MWth to 1 MWe)



What is an SMR?

Contrasts: large vs small

Large (Gen III, III+)	Small (Gen IV)
Economy of scale	Economy of multiples
One large station, single or multiple reactors	Several small reactors deployable in a fleet
Large fuel inventory	Small fuel inventory
Long construction times, reactors are often "tweaked" regular designs	Small "pre-fabricated" similar units in a factory setting (cutting on construction time)
Static, relatively large footprint	Small, self-contained units that can be moved in/out by land or by sea
Production and distribution via grid	Production at remote site; might not need extensive grid network

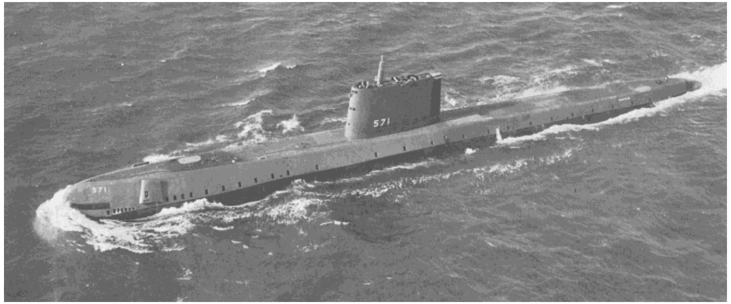
What is an SMR?

SMRs are not new: SMRs have been around the globe for 60+ years

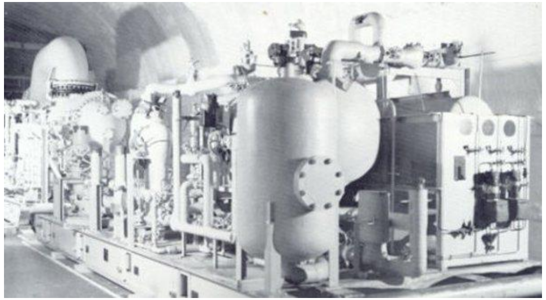
Submarines and surface vessels

- >140 ships are powered by more than 180 reactors (about 200 as per Lloyd's registry)
- 12000 reactor-year experience
- In the US alone, 6200 r-y of accident-free operation involving 526 reactors over 240 million kilometers.

…plus trains, planes and automobiles…



USS *Nautilus* (SSN-571) 1955-1980, the first nuclear submarine
Picture: Wikipedia



PM2A reactor at Camp Century, Greenland (1961-64): assembly of a SMR from prefabricated construction and transportation.
Source: https://apps.dtic.mil/dtic/tr/fulltext/u2/1064604.pdf
Picture: http://strangesounds.org/?s=camp+century

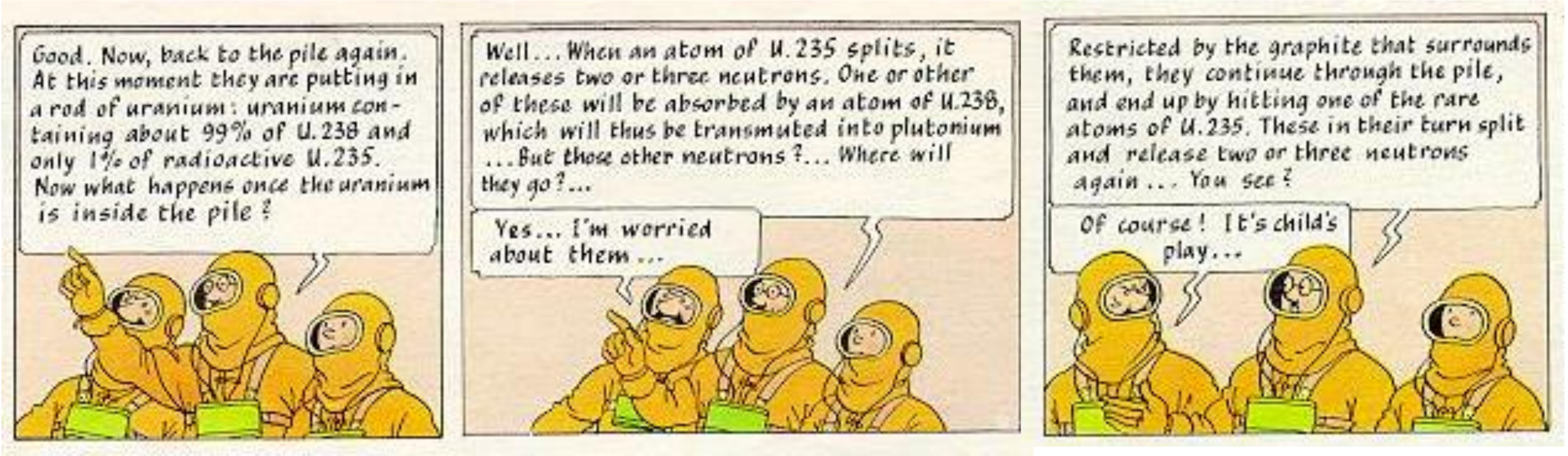
Source: World Nuclear Association

What is an SMR?

There are ~100 designs of SMRs under 4 general types:

Type	Coolant	Fuel	Other (oper. temp., etc)
BWR or PWR	Light water (Boiling or Pressurized)	Lightly enriched U (~5%), 2-5 year typical refueling cycle	Up to ~374 ^{o}C; pressurized; low technological risk
HTGR	High temperature gas – He or CO_2, graphite mod.	Enriched U (up to 20%) or Th; TRISO pebble-type fuel replaced continuously, 5-10 yr cycle	Capable of 700-950 ^{o}C
Liquid metal (fast breeder)	Na, or Pb-Bi metal	Most "burn" $^{235\ \&\ 238}U$, ^{232}Th & An; no enrichment needed, refueling cycle up to 20 yr	~480-570 ^{o}C; 50+ yr oper. experience; atmospheric pressure
Molten salt (MSR)	Li-Be-F salts, some designs use Cl salts; cryolite compatible	Liquid salt core with U-Th-F; can "burn" ^{238}U and An; no enrichment; on-line refueling	700 → 1400 ^{o}C; atmospheric pressure; FP removed off-line

What is an SMR?



What is an SMR?

Fission reactors (thermal or slow neutrons)

$$^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n}\ (\mathrm{thermal}) \rightarrow {}^{139}_{56}\mathrm{Ba} + {}^{94}_{36}\mathrm{Kr} + 3\ {}^{1}_{0}\mathrm{n} + \mathrm{Q}$$

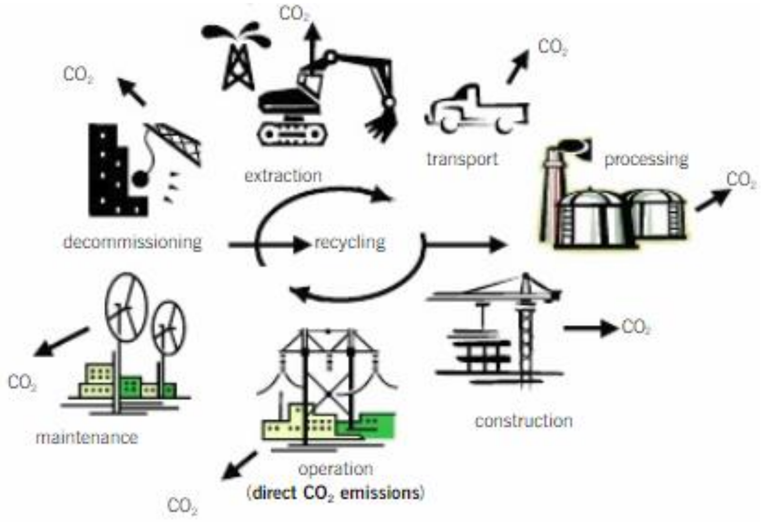
Fast breeding reactors:

$$^{238}\mathrm{U} + \mathrm{n}\ (\mathrm{fast}) \rightarrow {}^{239}\mathrm{U} \xrightarrow{\beta^-} {}^{239}\mathrm{Np} \xrightarrow{\beta^-} {}^{239}\mathrm{Pu} \rightarrow \rightarrow \ldots$$

$$^{232}\mathrm{Th} + \mathrm{n}\ (\mathrm{fast}) \rightarrow {}^{233}\mathrm{Th} \xrightarrow{\beta^-} {}^{233}\mathrm{Pa} \xrightarrow{\beta^-} {}^{233}\mathrm{U} \rightarrow \rightarrow \ldots$$

The needs for SMRs

- Environmentally sound;
- Zero GHG emissions during operation;
- Passive safety features – "walk-away" design;
- Economically sound;
- Deployment – especially in remote areas (no need for distribution infrastructure and maintenance);
- "cookie-cutter" construction;
- Saves on transportation and exploitation costs



https://www.scribd.com/document/36210065/Carbon-Footprint-of-Electricity-Generation-ghg

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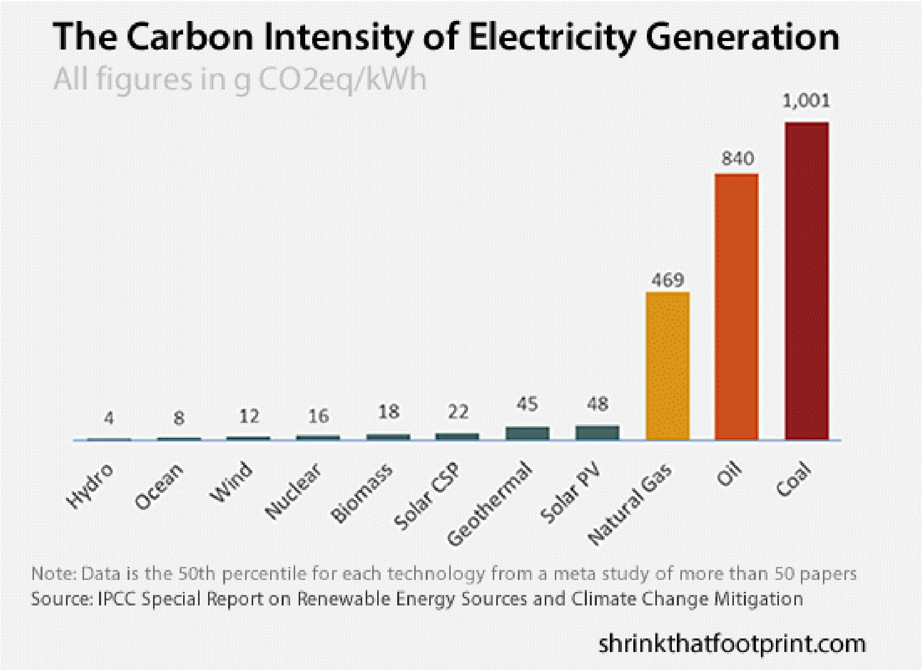

http://shrinkthatfootprint.com/greenest-electricity-source

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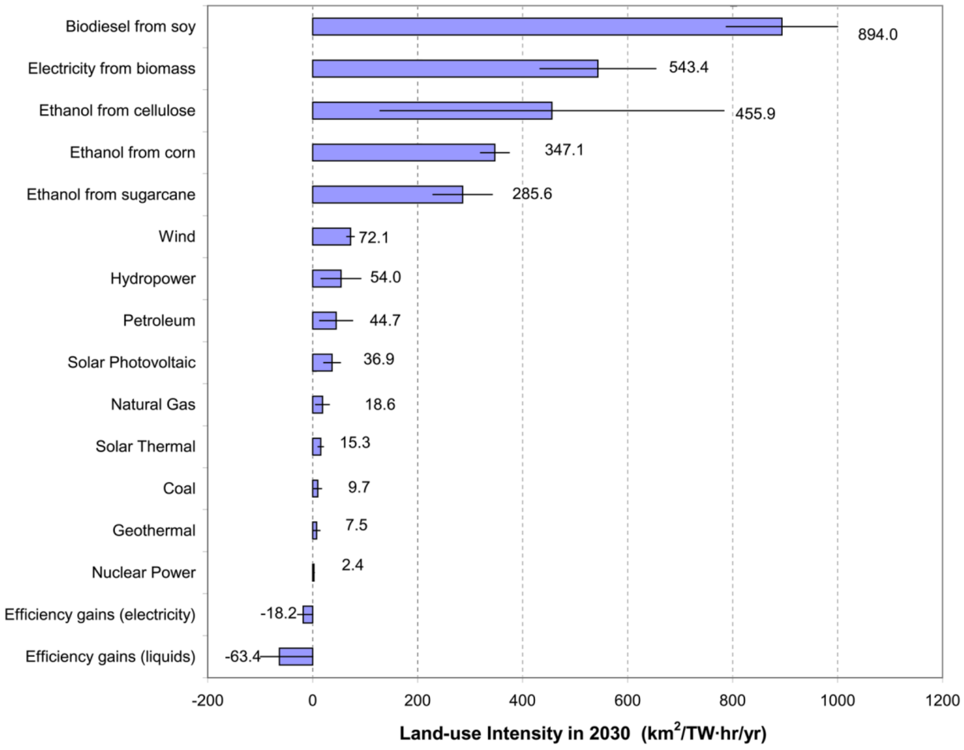

https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0006802
McDonald et al., Plosone.org, V4 Pe6802 (2009)

The challenges and innovation for chemists

Evolution of a mining project or operation

Exploration, discovery, economic viability, EIS, permits, etc.

Operation

Post-operation, closure, etc.

Need for SMR – licensing (CNSC REGDOC 1.1.1 & 1.1.5)

Mine operator identifies energy needs:

- Contacts reactor operator, responsibilities are defined in an MOU
- Both licensing & permit processes can be done in parallel
- SMRs: at the stage of proven concept (after demonstrations; “de-risked”)
- Example of case study (→)

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Need for SMR – licensing (CNSC REGDOC 1.1.1 & 1.1.5)

Proponent (vendor/operator):

- Information gathering;
- Apply site evaluation process, all applicable regulations;
- Baseline characteristics may be already available from exploration data

Application for license:

- Procedures are established;
- Maintain information during lifecycle

Post-operation:

- Mine and SMR post-operation have different timelines and requirements (MOU);
- SMR: decommissioning and environmental monitoring

There is a need for chemists and scientists at all stages!!

The challenges and innovation for chemists

Currently, there are:

~100 potential SMR vendors at different stages of conception

See:
wna.org

Ontarioenergyreport.ca
(Hatch SMR report)

11 vendors at various stages of review with the CNSC*

- Possibility to “fast-track” regulatory reviews from other jurisdictions

*CNSC: Canadian Nuclear Safety Commission

3 applications: invitation to site SMR demonstration units by CNL (as of February 2019)

- This is multi-tier rigorous process: it involves pre-qualifications on the merits of the design, financial, technical, security aspects
- Advanced stages involve risk management, execution, testing, operation, etc.

See CNL.ca

The challenges and innovation for chemists

The “new” chemistry:

- “boots-to-the-ground” in pre-assessment and exploration;
- Remote operation of SMRs and pre-tested measurement methods;
- Some SMR designs require additional research;
- Lifetime opportunities as a part of the CNL invitation process

Case study: the SMR Barge project at a remote mine

Reactor vendor/conceptor:
*Expertise for design & regulatory approvals
*Fast construction turnaround

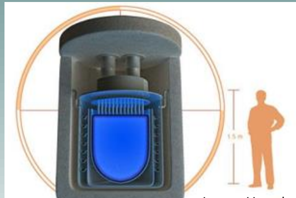
Image: Hyperion

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Mirarco's role and vision:
*Linking all
*Detailed business plan
*Calculations of environmental and dollar footprints

Mining Client (for ex.: near-shore)**:**
*Expertise and ethical exploitation
*Existing First Nations involvement

Experienced Operator:
*Licensing and operation
*Waste management & Decommissioning

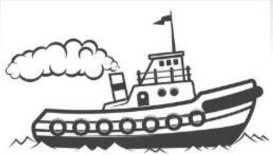
Shipping barge: expertise in designing offshore platform development for commercial nuclear power generation

Case study: the SMR Barge project at a remote mine

SMR at remote mine:

- Agreement with operator/provider
- SMR is used, re-fueled as needed (5-20+ years, depending upon design);
- Carbon savings over diesel for a mining project: a 20 MWe SMR can save annually $15 M and avert 140 ktons of CO_2 emissions (also averting fuel transport & footprint, plus the cost of a generator)*

*unpublished MIRARCO business case



Removal or recycling off-site, easy decommissioning and/or waste management.

Conclusions

The future is here

- SMRs and Gen-IV reactors represent a new and exciting opportunity: environmental, energy mix for the future, potential for waste reduction;
- SMRs are an attractive solution for remote communities: deployment, carbon savings, no need for an extensive distribution network;
- This is a new innovation opportunity for chemists and scientists:
  - Prequalification, operation, decommissioning;
  - New on-line and remote chemistry, streamlining analytical capabilities;
  - Be at the forefront of larger global environmental issues, e.g., life cycle analysis, energy portfolios, climate change, etc.
- MIRARCO's role: identify gaps – scientific research – economic assessment – linking mining clients to SMR vendors – case studies

Acknowledgements and further readings

- **MIRARCO.org**
  (watch video under “**Centers → Energy**”)
- **CNSC** – search for:
  “Pre-Licensing Vendor Design Review”
  “REGDOC-1.1.5”
  “REGDOC-1.1.1”
- **SMR roadmap:** smrroadmap.ca
- **CNL** expression of interest: search for “Perspectives on Canada’s SMR opportunity”