Miraco
MINING INNOVATION

Mining Innovation, Rehabilitation and Applied Research Corporation

About MIRARCO

MIRARCO (Mining Innovation, Rehabilitation and Applied Research Corporation) is a **not-for-profit research arm** of Laurentian University, Canada's Mining University.

Our team of talented **academic and industry professionals** offers **expertise** for applied research in **Rock Mechanics, Safety, Software, and Energy**.

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Laurentian University
Canada's Mining University

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Production of Electricity Using SMRs for Off-Grid Mining and Other Applications

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Small Modular Reactors (SMRs)

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

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

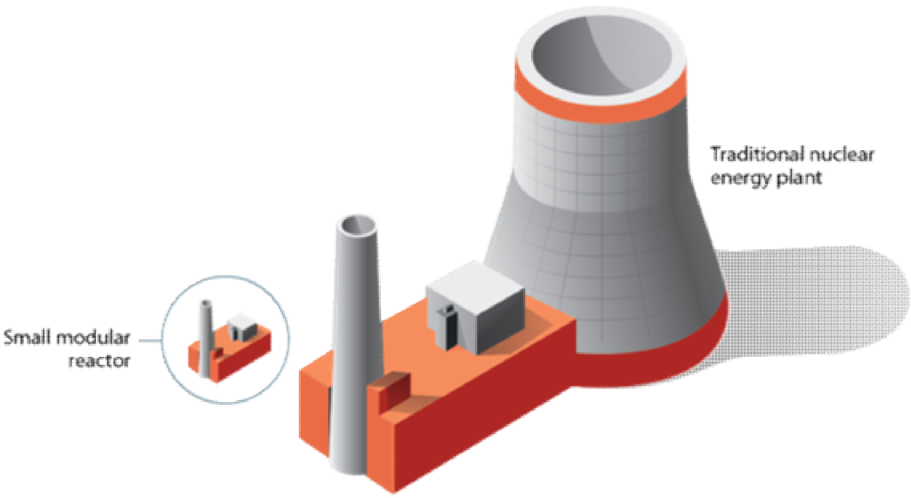
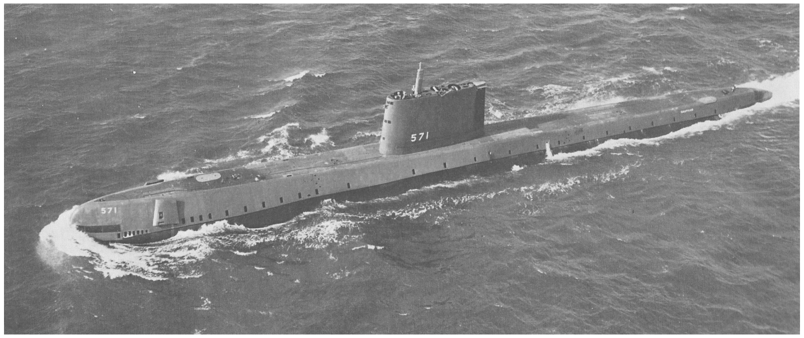


Image from Idaho National Laboratory

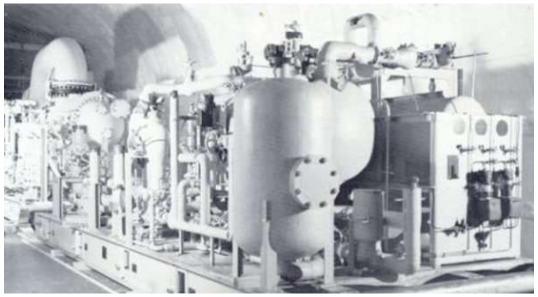
Small Modular Reactors (SMRs)

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.
- 35 MW reactor on floating platform in Russia since 2019



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

- Gen II type reactors built from 1960's to 1990's
  - >800 MW
- Nuclear Renaissance in early 2000's (Gen III and III+)
  - >600 MW
  - Improved safety but complex licensing and high cost
  - Refurbishment of Gen II reactors typical
- Gen IV Reactors - SMRs
  - Rethought
  - Lower capacity
  - Higher core energy yield
  - Smaller footprint
  - Centrally built and transported to point of use

Hyperion (left) and Babcock & Wilcox (right) Small Reactors.

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

Canadian Power Generation

- Hydroelectricity = 60%
- Nuclear = 15% (59% in Ontario)
- Coal = 9% (0% in Ontario)
- Gas/oil/other = 10%
- Renewables = 7%

SMR: Context and Needs

Oil sands

- Steam for SAGD and electricity for upgrading at **96 facilities**
- 210 MWe average size for both heat and power demands
- 5% replacement by SMRs between 2030 and 2040 could **provide** $350-450M **in value annually**

High-temperature steam for heavy industry

- 85 heavy industry locations (e.g. chemicals, petroleum Refining)
- 25-50 MWe average size
- 5% replacement by SMRS between 2030 and 2040 could **provide** $46M **in value annually**

Remote communities and mines

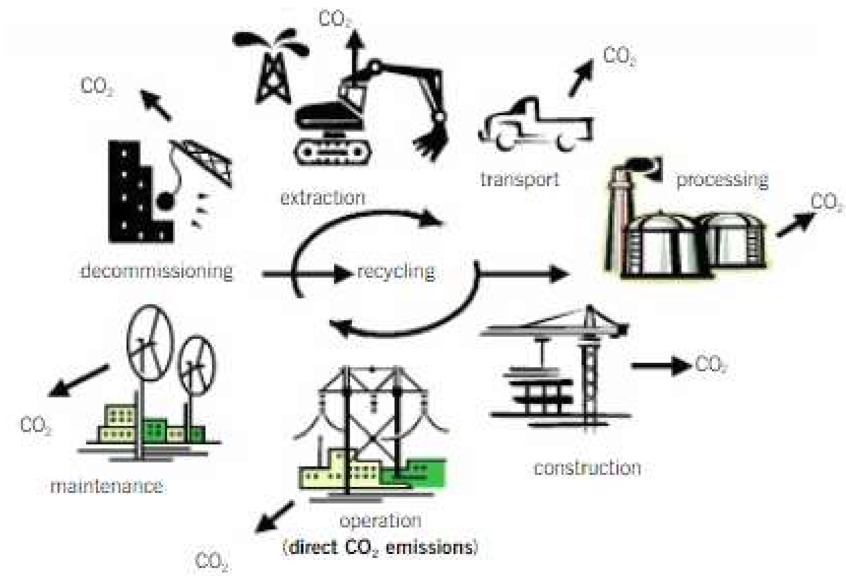
- 79 remote communities in Canada with energy needs > 1 MWe
- SMRs replacing costly diesel and heating oil could **reduce energy costs to the territorial government**
- **The high cost of energy from diesel is a barrier. SMRs could facilitate and enable new mining developments**
- 24 current and potential off-grid mines

Replacing conventional coal-fired power:

- 29 units in Canada at 17 facilities
- 343 MWe average size
- 10% replacement by SMRs between 2030 and 2040 could **provide** $469M **in value annually**

SMR: Context and Needs

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



Risks (1 of 2)

Safety and regulatory	• Strong track record, independent regulator • Zero (0) fatalities in Canada for 50+ years of operation
Operators of reactor	• Canada has experienced operators: Bruce Power, OPG, NB Power
Vendor readiness level (VRL)	• Vendors are experienced in reactor design, SMRs are re-engineered to be smaller; • Supply chain and QA are established
Technical readiness level (TRL)	• TRL 6-7 (out of 9) • CNL demonstration: 2 vendors are at advanced stage

Risks (2 of 2)

Financial

- First of a kind (FOAK): highest cost; other "copies" would be gradually less expensive
- Who will finance the first SMR?
- Perception: a demonstration prototype?
  *BP, OPG have licensed sites
  *CNL demonstration

Perception: waste management

- Waste issues have been well known for decades;
- Canada has spent $300 M+ to 1996 on the AECL deep geological disposal concept;
- NWMO has taken over in 2002: what do Canadians want (2005)
- Currently: site selection process (2 sites)

Economics

Economics

Engage with a mining company and assess their needs:

- CAPEX: cost of reactor, core replacement, backup, commissioning, licensing, waste management
- OPEX: operating personnel, security, fuel (and handling) for backup
- Externalities: Indigenous Rights, carbon savings, environmental impacts, impact on Community
- Explore other benefits: no need for building diesel infrastructure; can cheaper power extend life of mine?

Conclusions

SMRs for mining?

- The new generation of reactors, SMRs particularly, represent a new opportunity for remote mines:
  - Long lifetime for the reactor, low maintenance, zero emissions , small land footprint, Carbon savings, no waste at site (pack and go).
- Social acceptance and financial/economical risks are key:
  - Social acceptance: part of it is perception. Proper science communication and deep engagement with a Community and Indigenous acceptance are proposed;
  - Financial/economical: a mine owner engaging with an experienced operator will mitigate this risk, and potentially increase acceptance. A joint venture mine-community -operator could be explored?

Acknowledgements and further readings

Innovation at work

- **MIRARCO.org**
  (watch video under "**Centers → Energy**")
- **SMR roadmap:** smrroadmap.ca
- **CNL** expression of interest: search for "Perspectives on Canada's SMR opportunity"
- Ontario Energy report (Hatch), google "SMR Deployment Feasibility Study"

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