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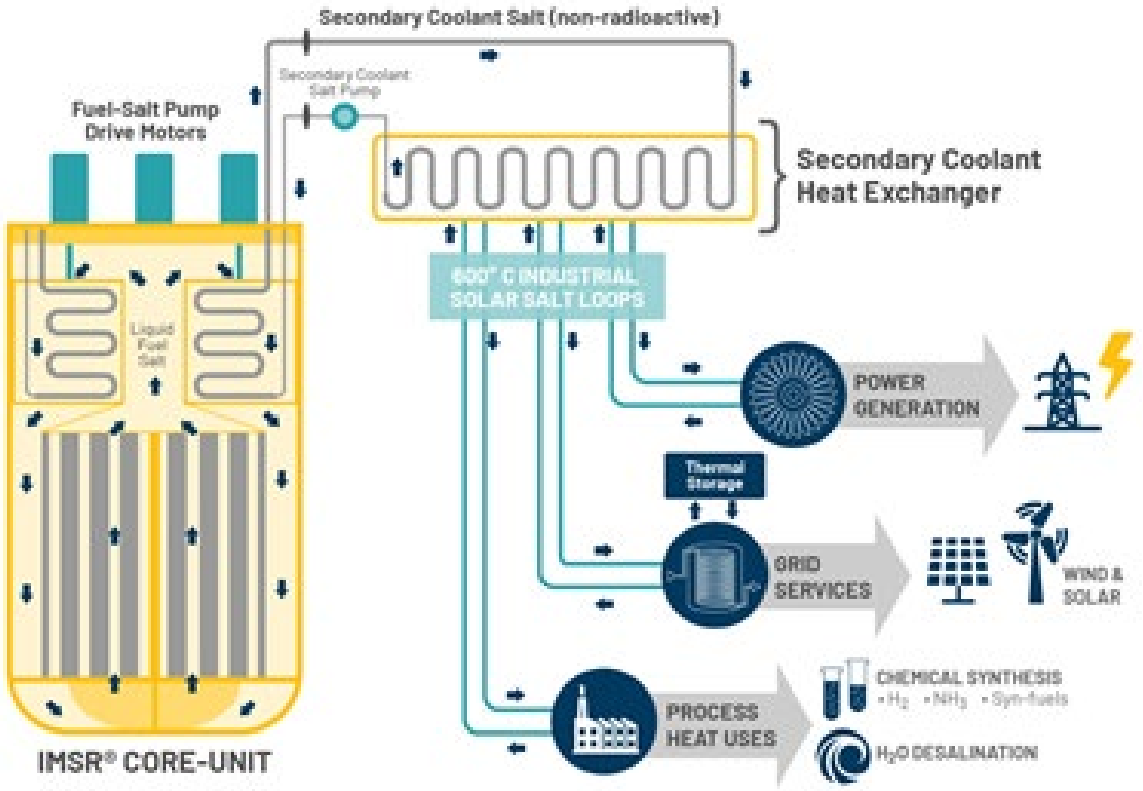
Small Modular Reactors

Application to Mining and the North

Small Modular Reactors

- Intro
- SMRs
- Discuss need
- A few types
- A possible path forward



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When Asked About Nuclear

- Most people:
  - Flinch
  - Avoid the issue (and eye contact)
  - Start to tell me what's wrong with Nuclear
    - Cost
    - Godzilla
    - Fukashima, Chernobyl and Three Mile Island
    - Nuclear weapons
    - Radiation
  - Regardless - admit benefits v.v. Climate Change

When Asked About Nuclear…..

- I tell them to forget about the ‘old’ nuclear
- Focus on what’s new and different:
  - Generation 4
  - Small Modular Reactors - SMRs
  - Changes that make them
    - Lower risk
    - Safety in ‘aircraft like’ production QC
    - Portability
    - Simpler design and construction
  - Reinforce the Climate Change benefits

SMRs

- Small Modular Reactors
  - Nuclear reactors, ≤300MWe (range 4 to 300MW$_e$)
  - Generally use slightly enriched or low enriched uranium
  - Modular – scalable through multiple units
  - 'Mass' producible – production line assembly
  - Relatively portable units – large truck size
  - Most use 'inherently safe' technologies
  - Most run hot – produce a lot of heat (600 – 700^{o}C)
  - Civil works are simpler
    - Don't generally need containment structures
    - Don't need larger exclusion zones

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To Be Clear

- SMRs are part of the energy solution
  - We will need a full energy mix
- Complement renewables and natural gas
  - Load following capabilities
- Can play a significant role in GHG reduction
- Have some specific applications
- May have competitive per MW costs
  - If current estimates accurate

Why Right Time?

- Current Fleet of Large Plants
  - Coming to end of life/require refurbishment
  - Expensive to build as all one-of-kind builds
    - Huge cost overruns recently
    - Finnish reactor estimated to be $12.5B for 1100 Mw_e
  - Relatively complex technology
  - Risk of meltdown (e.g. Fukashima)
  - Either continuously refuelled (Candu) or every two years
  - Spent waste a problem – highly radioactive

Why Right Time

- **Old Nuclear has lots of baggage**
  - Nuclear development legacy
  - Many designed specifically to provide countries with nuclear weapons materials
- **SMRs can address some current issues**
  - Energy needs
  - Scalable – support renewables
  - GHG commitments

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Climate Change

- **Need for GHG free energy**
  - Huge driver
  - Can replace/supplement fossil fuel generated power
- **SMRs produce power with low carbon inputs**
  - Manufacturing
  - Transport
- **Supports renewables**
  - Need for base load
  - Load following capabilities
- **Offsets could be applied to national/provincial reduction targets**

Alberta Oil Sands Example

- **If production of 1.3 million barrels per day from SAGD**
  - Requires 110 kg CO_{2e}/bbl (production + upgrading)
  - Or 52 M tonnes CO_{2e}/year
- **If \$50/t CO_{2e}**
  - Then cost is \$2.6 billion/year in carbon taxes
- **SMRs**
  - Developed using carbon credits
  - Offsets applied to industry
    - Open up new production allowances under 100 Mt cap
  - Heat can produce steam for production/H_2 for upgrading
  - Still heat for co-generation
  - GHG offsets help provincial and national goals

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Northern and Remote Sites

- Often off the electrical grid
- Renewables costly and inefficient
- Power supplied by diesel generators
  - Diesel has to be brought in seasonally and stored
    - Can be subject to the vagaries of weather
  - Expensive!
    - More so if it has to be flown in
  - Risk of spills and accidents
  - Can be noisy and produce exhaust/localized pollution

Northern and Remote Sites

- SMRs – can be sized appropriately to locale
    - Currently a variety of models to choose from
- Could be shipped by road, rail, ship or aircraft
- Civil supporting works are relatively simple
    - Manageable in a remote location
- Provides heat and electricity
- Periods between refueling relatively long (7 to 20 years)
- Spent modules removed from site - recycled
- Can be quiet, secure and noise free

E.g. - Northern Saskatchewan

- Northern grid maxed
- Likely unable to support new mines or development
  - Means power generation using diesel or LNG generators
  - Or expensive power grid upgrades
- A well placed SMR(s)
  - Provide a stable grid
  - Reliable base load power
  - Heat for processing

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Mines

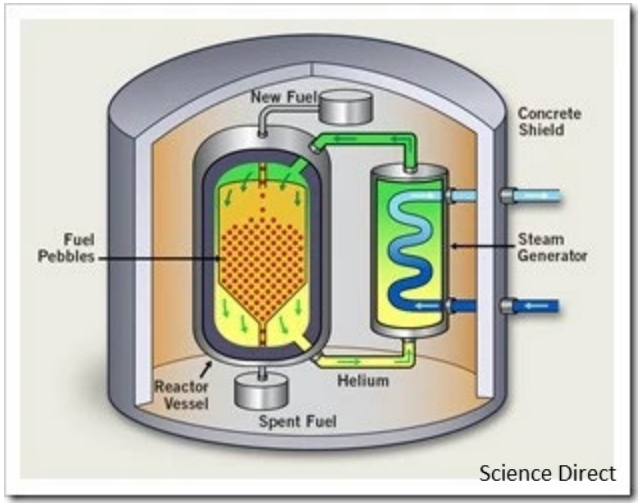
- Often northern and remote
- Require stable power that can support operations
  - Hoists
  - Process machinery start ups
  - Mill machinery
  - Electrification of U/G operations
- Power lines subject to lightning strikes/accidents/fire
  - Require back-up power
- All fuels need to be transported to site

Mines and SMRs

- Scalable units
- Produce heat
  - Electrical generation
  - Heating shafts in winter to prevent freezing or conditioning air
  - Process heat
  - Heat to accommodations and offices
- If on grid – can supply excess power and recover some costs

SMRs

- Several technologies being developed
  - Not new for the most part, but improved
- Advanced Light Water Reactors (Mini-PWRs)
- Variations on molten salt technologies
- Pebble beds with various coolants



Advanced Light Water Reactors

- **Nu-Scale**
  - Current front runner in US
  - Is working with CNSC on the design verification stage
- **Not my favourite**
  - Needs a containment vessel
  - While self circulating, needs water as a coolant
  - Needs low enriched fuel ($\leq$ 4.95% U^{235})
  - Mechanically complex compared to other options
  - Runs cool compared to other SMRs (<300C)
    - Don't get the benefit of heat for other processes

Molten Salt Technologies

- **Variations on molten fluoride salts mixed with a uranium-fluoride salt**
- **Produces heat**
  - Run long and hot, and burn through some progeny
  - Many self-circulating, most not water cooled
- **Relatively simple infrastructure – no containment vessel**
- **If containment break, no gases,**
  - At worst: passive dissipation of nuclear heat

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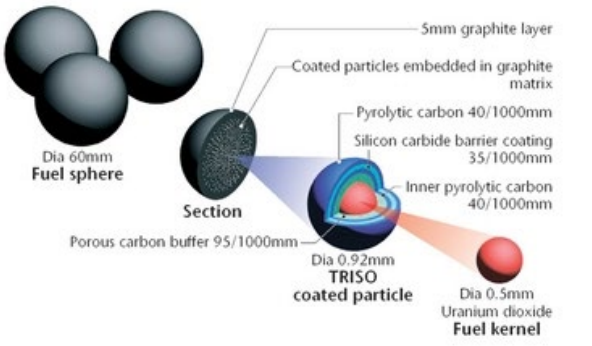
Molten Salt Technologies

- **Canada**
  - Terrestrial Energy's Integral Molten Salt Reactor
    - Pursuing licensing in US and Canada
    - Uses graphite as a moderator with replaceable core
    - Based on a tested design from Oak Ridges Lab in US
- **Britain**
  - Moltex – vented molten salt technology
    - Can use spent reactor fuels as fuel
    - Continuous refueling
    - Produces a waste that only needs 300 years storage
    - New Brunswick has shown some interest and invested research $

Pebble Bed Type

- **URENCO U Battery**
  - TRISO pellets
    - Small uranium core (0.5mm) wrapped in ceramic coatings and graphite shell
    - Very strong, spherical
  - Helium and nitrogen cooling
  - Smaller units (~10-Mw_e)
  - Easily scalable with multiple units
  - TRISO pellets good to 1800°C (>200°C over maximum accident scenario)



Science Direct

Other SMRs

- **There are a lot under development**
  - Many countries working on SMRs
    - US, Canada and Britain
    - Also Japan, Korea and others
  - Actively being built in China and Russia
    - Not apparently hindered by regulators or cost
    - Russians putting on ships to power remote communities
  - Would rather see Canada develop technology
    - Become a leader in this field

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Practical Uses of SMRs

- **Oil Sands - especially SAGD**
  - Process heat for thermal release of oil
  - Waste heat still hot enough for co-generation
- **Oil and Gas/Hydrogen fuel**
  - Hot enough for hydrogen production
- **Distillation of sea water/water purification**
  - Lots of heat
- **Distributed power grids**
  - Many smaller units in a stable power grid – perfect for SK

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Encouraging Signs

- Interest in SK, AB, NB and ON
  - Fedoruk Centre for Nuclear Innovation
  - But, mostly just interest
- Some grant money from governments – NB and Moltex
- Several entering CNSC design validation process
- Indications of interest in testing at CNL, Chalk River
- More conferences, better attended
- Canadian politicians interested – but not overtly
- Some moving to licensing in the US – US more aggressive
  - Legislation to accelerate advanced reactor deployment

Discouraging Signs

- New age of Luddites?
  - NIMBY: Not In My Back Yard
  - BANANA "*Build Absolutely Nothing Anywhere Near Anything/Anyone*")
  - Decline of scientific and technical literacy
  - Fake news - Orwellian
- Cheapness of natural gas
- Nuclear legacy still haunts
- Nuclear knowledge retiring
- Government's unwillingness to fund/support

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Something to Think About

- Site C Dam will cost $11+ billion (current estimate)
    - Produce 1100 Mw_e (maximum output)
- This is the approximate cost and power output of the Finnish Olkiluoto Nuclear Power Plant
- $11B would fund approximately 8 FOAK SMRs
    - Could produce >>1100 MW_e and MW_t
    - Less environmental impact!
    - Support SK U mining industry
    - Develop Canada as an SMR leader

Site C Joint Panel Said:

Site C "*would produce fewer greenhouse gas emissions per unit of energy than any source save nuclear*."

But that doesn't consider the project's impacts from:

- Damming the Peace River
- Downstream impacts – Athabasca Delta/Wood Buffalo NP
- Establishment of reservoirs (85km^2+)
- Methane from rotting vegetation
- The huge quarries required to support the construction
- Etc.

Conclusion

- **SMRs need a financial backing to get going**
    - Someone (government?) to help with FOAK costs
- **Government also has to publicly support option**
    - Backed by a strong national regulator
    - But - Silence is damning
    - Yet behind the scenes government's say they are in favour – interested
- **Need companies to take the leap**
    - May if government supports concept

Conclusion

- **SMRs offer a potential GHG-free power source**
  - Relatively safe
  - Ideal for scalability and/or isolated locations
  - Support renewables
  - Process heat for electricity and other uses
  - Hydrogen fuel, desalinization, industrial processes, SAGD
  - Cost competitive
- **Canada could be a leader in their use and deployment**
  - Could beat US at this – there is still time

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