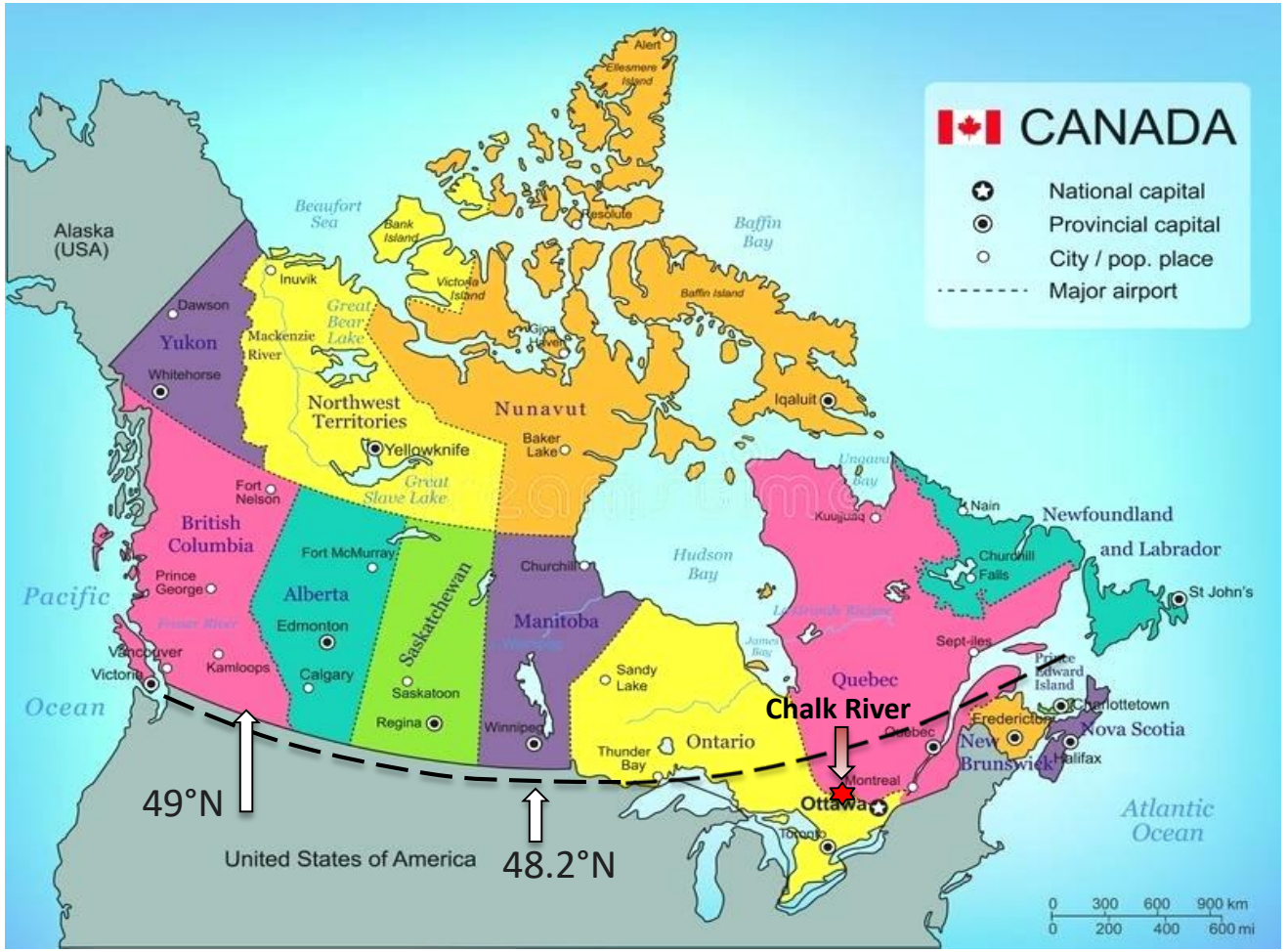
Recent Developments in Small Modular Reactors in Canada

Metin Yetisir, PhD
Section Head, Advanced Reactor Technologies
Research & Development
Canadian Nuclear Laboratories

Canadian Nuclear Laboratories | Laboratoires Nucléaires Canadiens

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Canada



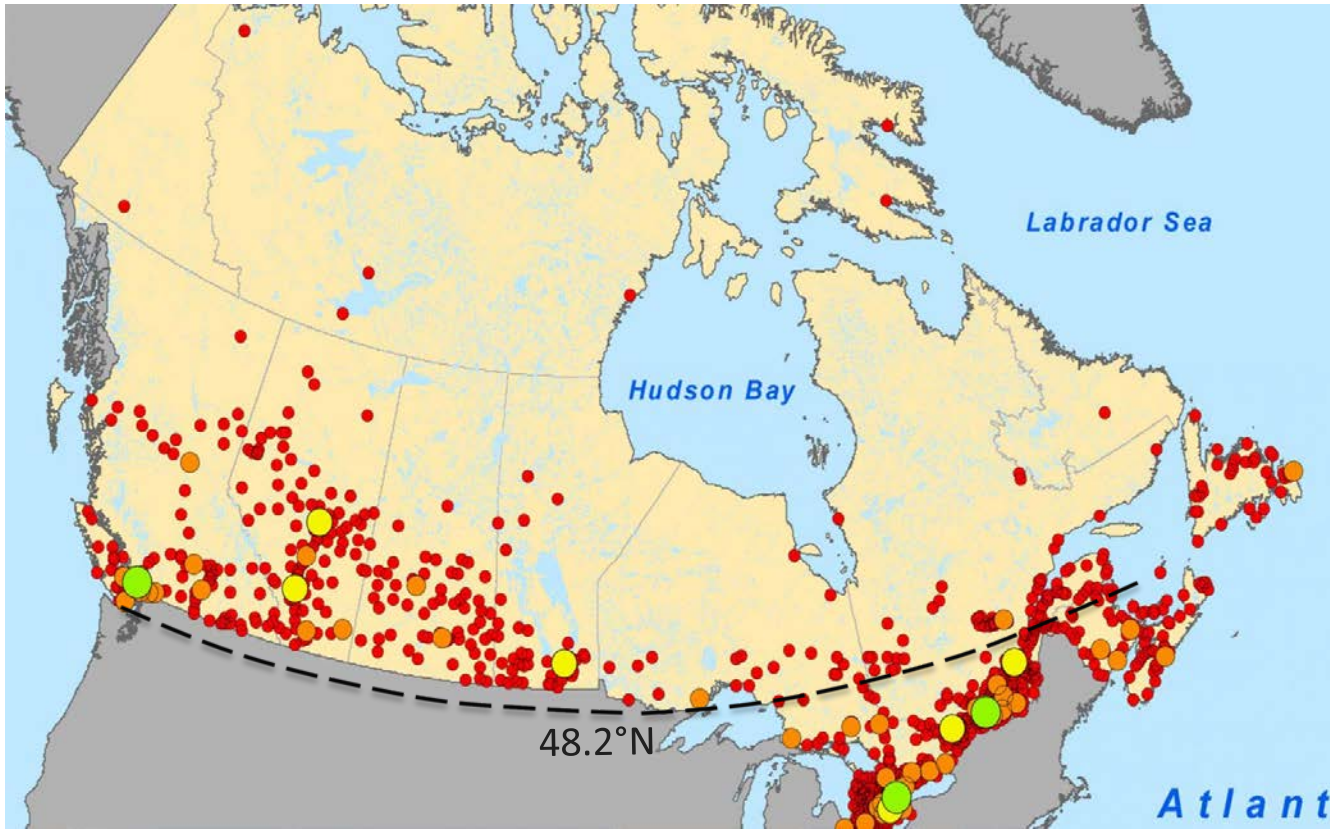
- Second-largest country in the world by total area
- 10 provinces and 3 territories
- North America's second largest economy!!!

- Latitude of Vienna: 48.2° N
- Latitude of Chalk River: 46.0° N

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Canada



- Low in population density (except the 200 mile band north of US border)
- Rich in natural resources. A $56B industry in 2015.
  Worldwide:
  - First in potash
  - Second in Uranium and Niobium
  - Third in nickel, gemstones, cobalt, aluminum and platinum group metals
  - Fourth in indium and sulphur
  - Fifth in diamonds, titanium and gold
  - Sixth in oil production

Northern Canada



- rich in natural resources, low in population density,…
  …and difficult to get access to…

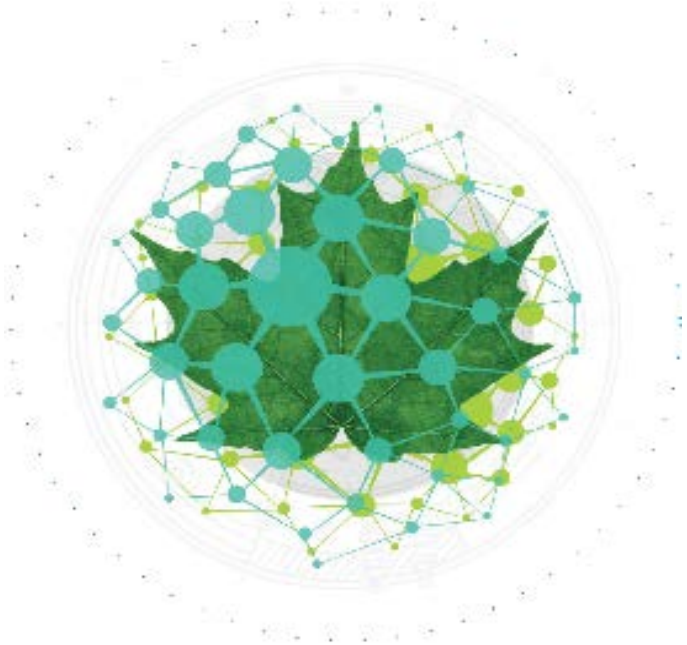


- Relies on expensive diesel power
- ~200 communities

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Drivers for Nuclear Power and Small Modular Reactors (SMRs) in Canada

Climate Change

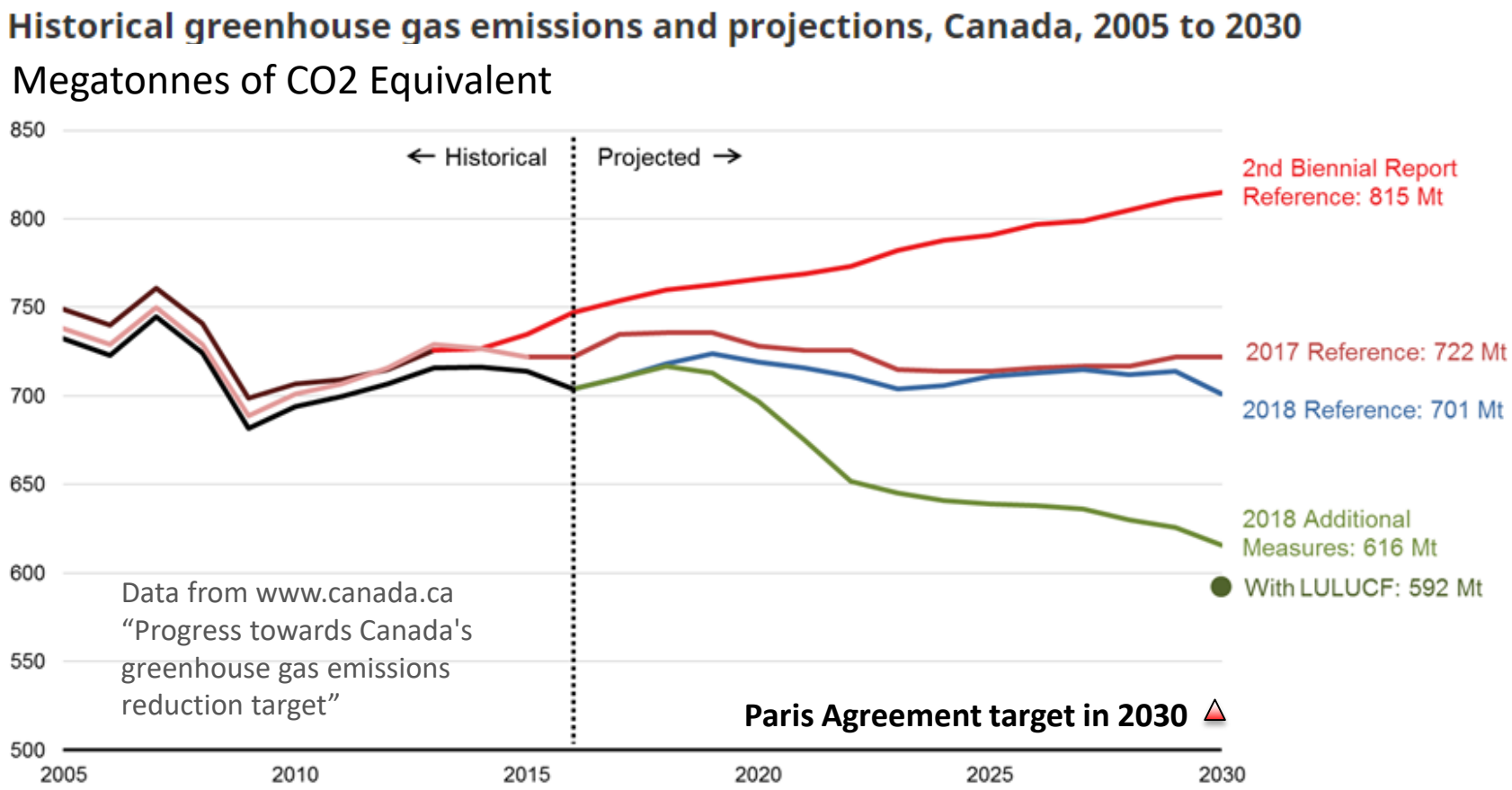


- The International Energy Agency projects that nuclear energy will need to double within 20 years to meet a climate target “smaller than 2°C temperature increase by the year 2100”

- International Energy Agency (2017) World Energy Outlook, Paris, France. https://www.iea.org/weo2017/

Climate Change - Canadian Government is Committed to Action, but additional measures are needed

- Government of Canada ratified the Paris Agreement, COP21 in 2015
- Under the Paris Agreement, Canada has committed to reducing its GHG emissions by 30% below 2005 levels by 2030



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Pressing Domestic Need



1. On-grid power generation to replace fossil fuels (~150-300+ MWe)



2. On and off-grid energy for resource extraction and industry: for example, oil sands or metal mining (~10-250 MWe)

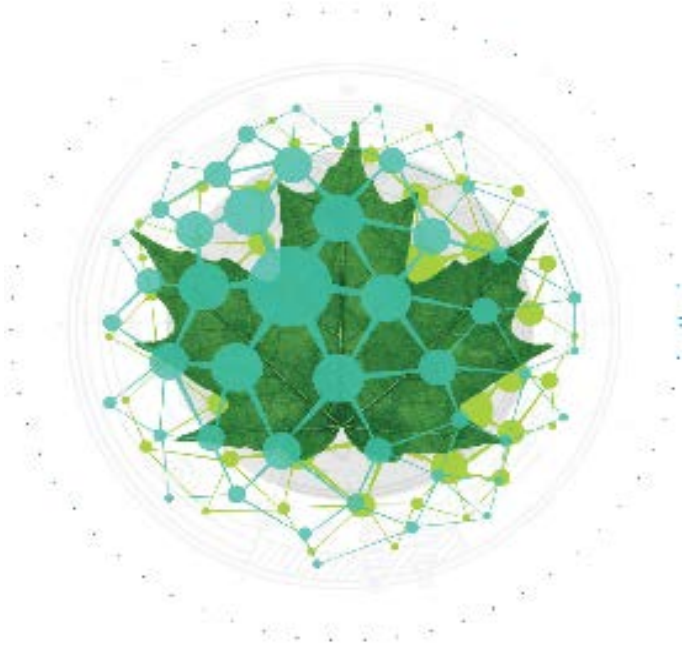


3. Off-grid diesel replacement for electricity, district heating, and desalination in willing remote communities (<10 MWe, many <2.5 MWe)

Small Modular Reactors, or SMRs, could be the answer

www.smrroadmap.ca

- In Canada and around the world, markets are signalling a need for smaller, simpler, and cheaper nuclear energy
- At the same time, demand for nuclear energy is poised to grow with global action on climate change
- SMRs are not the same nuclear reactors we have seen in the last half-century. They are innovative technologies that promise to help enable the clean energy transition.



Essential Elements Supporting Small Modular Reactors (SMRs) in Canada

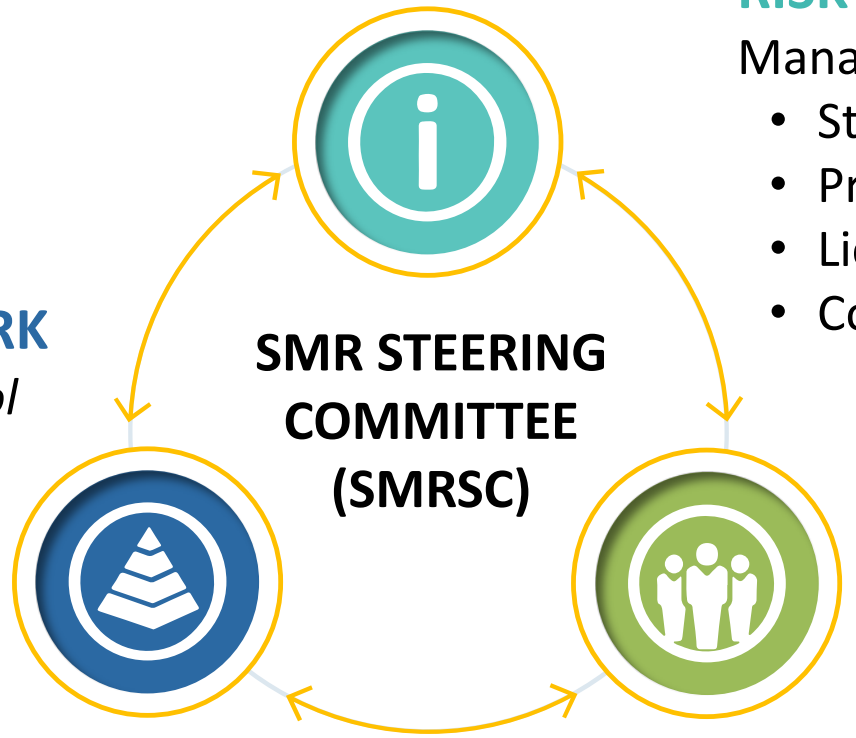
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Regulations - Canadian Nuclear Safety Commission (CNSC) is prepared to regulate Advanced Reactors and SMRs

ROBUST BUT FLEXIBLE REGULATORY FRAMEWORK

- *Nuclear Safety and Control Act* (NSCA)
- Regulations
- Licences
- Regulatory documents (REGDOCs)



RISK-INFORMED PROCESSES

Managed processes covering:

- Strategic decision making
- Pre-licensing
- Licensing compliance
- Continuous improvement

CAPABLE AND AGILE WORKFORCE

- Capacity/capability
- Training
- International cooperation
- Work organization

Regulatory Readiness - CNSC Activities and Engagements

STAKEHOLDER ENGAGEMENT

- discussion paper DIS-16-04, *Small Modular Reactors: Regulatory Strategy, Approaches and Challenges*
- stakeholder workshops: Graded Approach, Robustness, Security by Design (planned for Fall 2019)
- REGDOC-1.1.5, *Licence Application Guide: Small Modular Reactor Facilities*

SMR COMMITTEES

- to provide strategic direction and senior management oversight and support to the programs associated with SMRs
- rendering technical interpretations of the requirements and expectations in regulatory documents

VENDOR DESIGN REVIEW PROCESS

- allows early engagement with the CNSC – Currently 11 SMR vendors are either going through VDR review or in discussion with the CNSC

Nuclear R&D - Canadian Nuclear Laboratories' Chalk River Site is going through a $1.2B infrastructure renewal

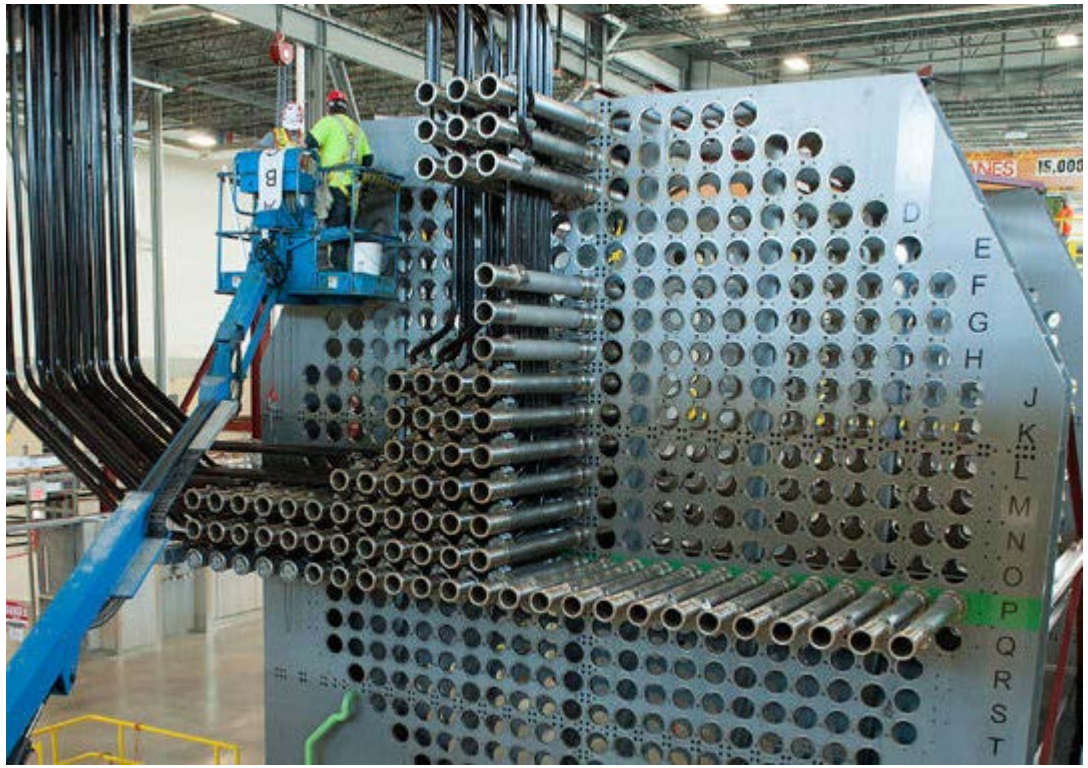
- CNL has identified SMRs as one of eight strategic initiatives with the goal of siting an SMR on one of the sites it manages by 2026
- One of the goals is to make the Chalk River site a global hub for SMR technology development and prototype deployment



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Mature Nuclear Technology and Supply Chain



- There are 18 CANDU reactors operating Canada.
- Active workforce: Ontario Power Generation and Bruce Power are spending ~Cdn$26B for refurbishment and life-extension of CANDU reactors
- Supply chain is well developed and active with refurbishment activities. Organised under the umbrella of the Organisation of Canadian Nuclear Industries (OCNI).

Federal Government Support

- Constitutionally nuclear energy falls within the jurisdiction of the federal government
- Natural Resources Canada is responsible for developing Canadian policy on all energy sources
- Canada advances its international engagement through instruments and activities across several departments and agencies

Key departments and agencies:

- Global Affairs Canada
- Natural Resources Canada
- Canadian Nuclear Safety Commission
- Atomic Energy Canada Limited
- Health Canada

Instruments and activities:

- Bilateral Nuclear Cooperation Agreements, MOUs, and action plans
- Multilateral engagement, peer review
- Diplomatic and trade missions

Provincial Interest in Nuclear Power and SMRs - Ontario

- 60% of electricity is produced by nuclear power plants (CANDU reactors)
- Ontario is committed to maintaining nuclear energy in its supply mix and pursuing innovative technologies.
- Small modular reactors (SMRs) have the potential to offer clean and reliable energy for on-grid, off-grid and industrial applications.
- Ontario Ministry of Energy study “Feasibility of the Potential Deployment of Small Modula Reactors (SMRs) in Ontario”

  http://ontarioenergyreport.ca/pdfs/MOE%20-%20Feasibility%20Study_SMRs%20-%20June%202016.pdf

  “… the economic competitiveness analysis shows that all SMRs are competitive against diesel power generation technology”

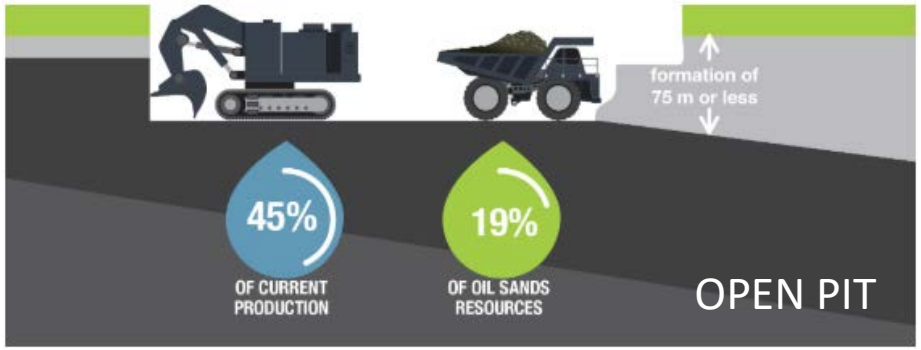
Provincial Interest in Nuclear Power and SMRs – New Brunswick

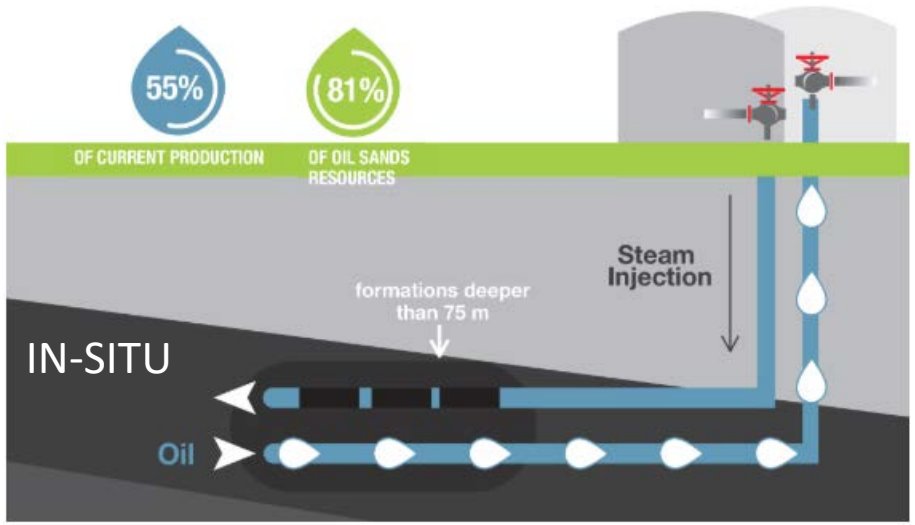
- 30% of electricity is produced by nuclear power plants (CANDU reactors)
- In 2018, the provincial Government of **New Brunswick** invested $10 million to help establish New Brunswick as a leader in the field of research and development of small modular reactor (SMR) technology. A nuclear research cluster (NRIC) was created in the province
  - ARC partnered with the Nuclear Research and Innovation Cluster of NB,
  - Moltex also partnered with the NRIC and chose NB as it's demonstration site,
  - University of New Brunswick - Centre for Nuclear Energy Research (CNER)

Provincial Interest in Nuclear Power and SMRs - Saskatchewan

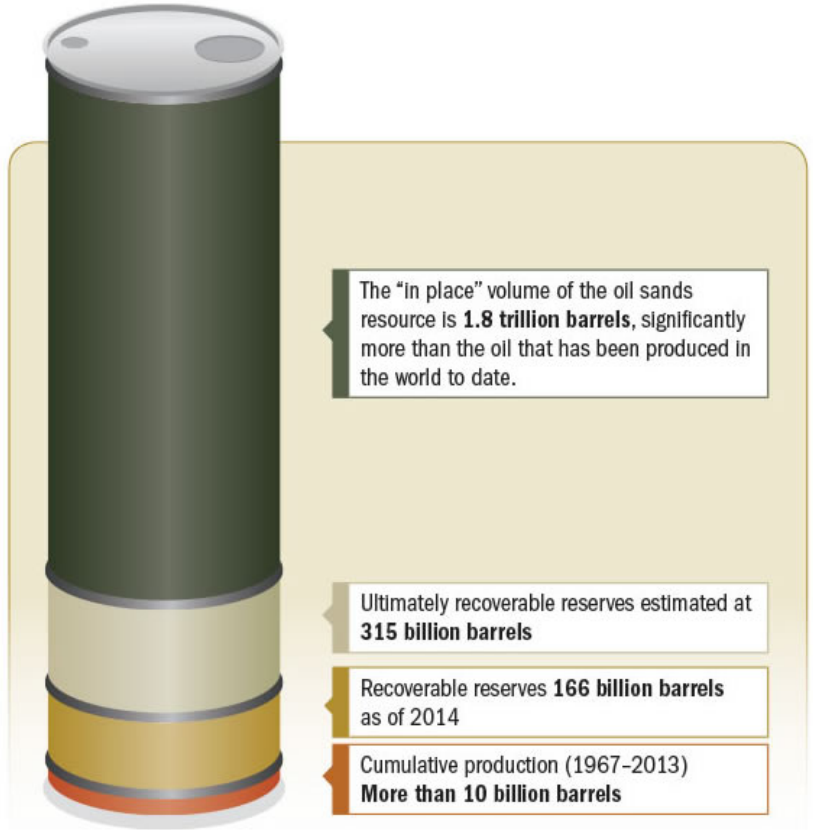
- Saskatchewan has large deposits of uranium and exports uranium,
- Saskatchewan government is in discussion with Ontario and New Brunswick about small modular nuclear reactor technology and considering SMRs as an option to replace coal,
- Fedoruk Center for Nuclear Innovation in Saskatchewan promotes nuclear medicine, materials science, nuclear energy systems including small reactor design, and environmental and social topics related to nuclear technology.

Additional Provincial Interest in Nuclear Power and SMRs - Alberta





- **Alberta Innovates** commissioned two studies as a possible means to reduce GHG emissions from oil sands



- In 2017, world annual oil consumption was 35 billion barrels
- Alberta produced ~1 billion barrels of oil

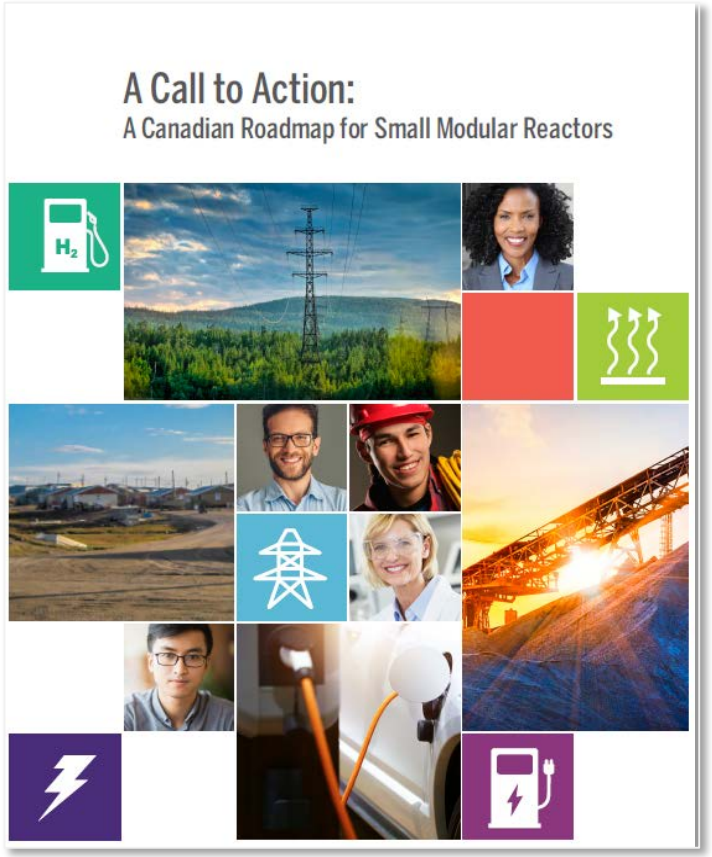
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Territories Interest in SMRs - Nunavut ands NWT

- **SMR Roadmap Document**: "*Territories (Qulliq Energy Corporation in Nunavut and the NW Territories Department of Infrastructure) are looking at all options*."





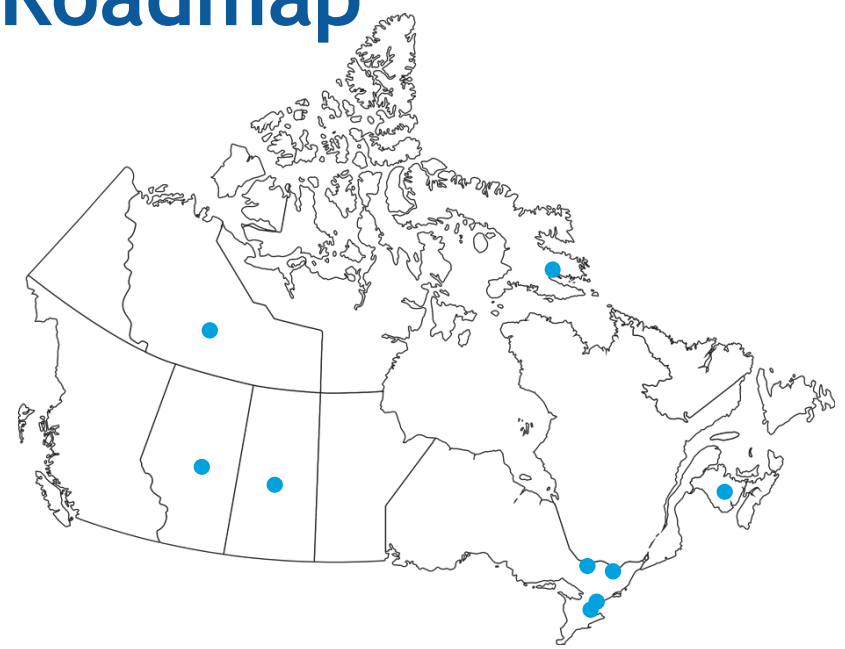
Pan-Canadian SMR Roadmap (2018 November)

www.smrroadmap.ca



Canada's Small Modular Reactor (SMR) Roadmap

- Facilitated by Natural Resources of Canada,
- One year, multi-stakeholder effort
- 180 Individuals representing 55 organizations
- 4 Provinces, 2 northern Territories, 5 electric power utilities
- Canadian Nuclear Safety Commission observed and clarified regulatory points



SaskPower Powering the future

nwmo NUCLEAR WASTE MANAGEMENT ORGANIZATION / SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

cna canadian nuclear association

Bruce Power Innovation at work

Qulliq Energy Corporation / Société d'énergie Qulliq / Qulliq Alruyaktuqtunik Ikumatjutiit

Natural Resources Canada / Ressources naturelles Canada

Canadian Nuclear Laboratories / Laboratoires Nucléaires Canadiens

ORGANIZATION OF CANADIAN NUCLEAR INDUSTRIES OCNI Clean Energy for a Low Carbon Economy

COG

ONTARIO POWER GENERATION

Alberta Energy

Ontario MINISTRY OF ENERGY

Énergie NB Power

ALBERTA INNOVATES

AECL

New Brunswick / Nouveau-Brunswick CANADA

Government of Northwest Territories Department of Infrastructure

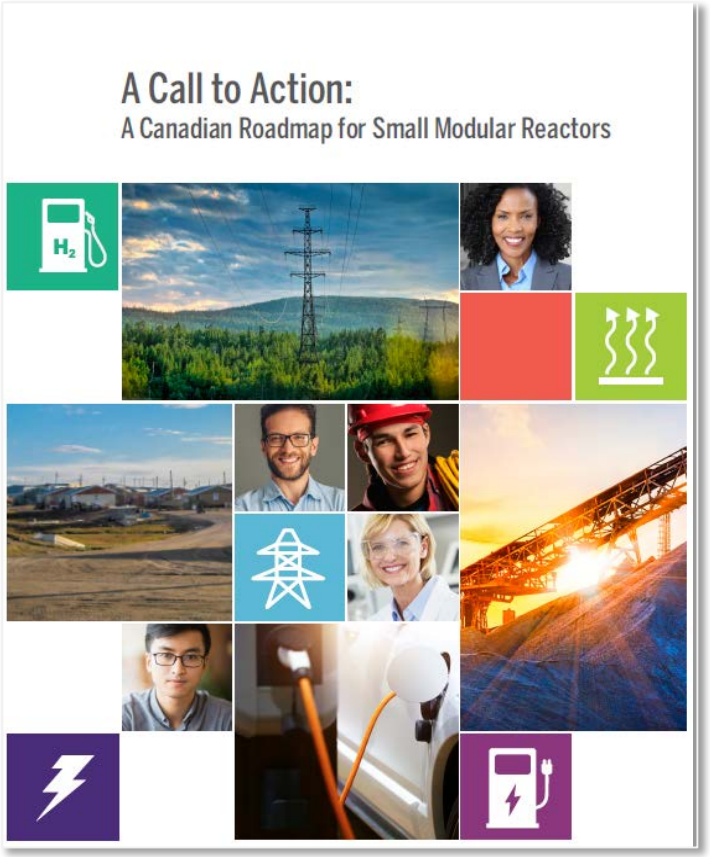
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Canada's Small Modular Reactor (SMR) Roadmap

- Canadian SMR Roadmap was released in 2018 November
- The vision: SMRs as a source of safe, clean, affordable energy — opening opportunities for a resilient, low-carbon future and capturing benefits for Canada and Canadians





Canadian SMR Roadmap https://smrroadmap.ca/

SMR Roadmap charts a national path forward for SMRs. High-level findings:

- SMRs are real and happening now
- Canada's existing legislative, policy, and technical framework around waste management is sound.
- Canada's technical solution for long-term disposal of spent fuel waste is sufficiently flexible to accommodate new fuel types from SMRs
- Canada's domestic market potential for SMRs is significant, and SMRs could be economically competitive.

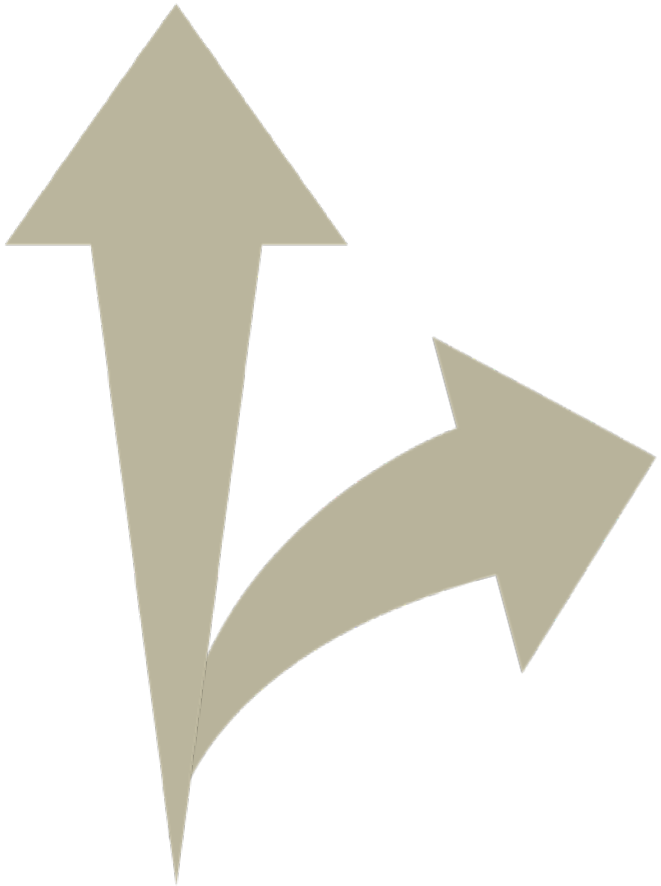
Canadian SMR Roadmap - Key players

To move forward, key players must act in concert:

- federal, provincial and territorial governments,
- Crown corporation (Atomic Energy of Canada Limited),
- Canada's nuclear science and technology organization (Canadian Nuclear Laboratories), and
- many others in the public and private sectors including energy utilities, technology developers, universities and laboratories.

The Roadmap report makes recommendations for each essential enabling partner

Canadian SMR Roadmap - Markets



Domestic Market

$19B/year impacts & 6,000 jobs

International Market

$150B/year global exports

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Canadian SMR Roadmap - Four thematic pillars

Recommendations are provided across four thematic pillars to guide future actions needed by governments, industry, and other nuclear stakeholders:



*Pillar 1

Demonstration & Deployment

Pillar 2

Policy, Legislation & Regulation

Pillar 3

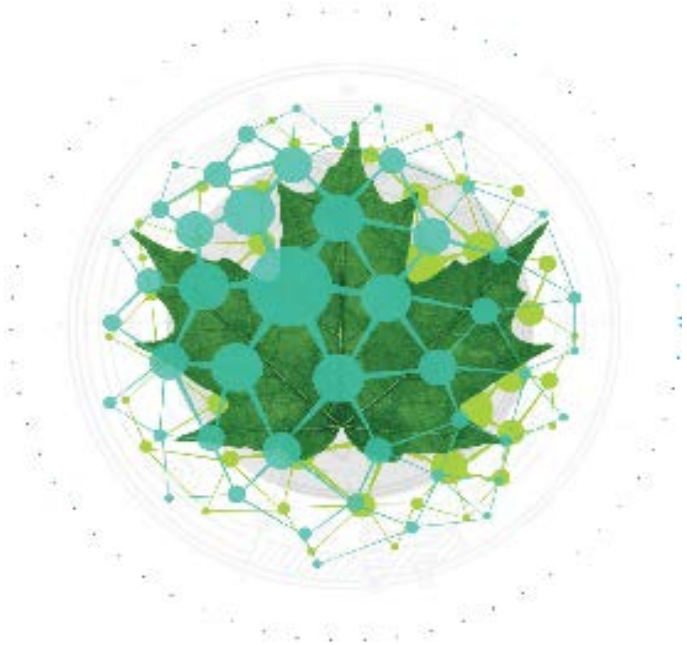
Capacity, Engagement & Public Confidence

*Pillar 4

International Partnerships & Markets

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SMR Technology Developers in Canada

Current Canadian SMR Status: Vendor Design Review
(7 service agreements are in force)

No	Country of origin	Company (Design)	Reactor Type	Elec. Output	Status
1	Canada/ U.S.	Terrestrial Energy (IMSR-400)	Molten salt (graphite moderated)	200 MWe	PHASE 1 - Completed PHASE 2 - Assessment in progress
2	U.S.	Ultra Safe Nuclear (MMR-5)	High-temperature gas cooled (graphite moderated)	5 MWe	PHASE 1 - Completed PHASE 2 - Project start pending
3	Sweden/ Canada	LeadCold (SEALER)	Lead cooled (fast spectrum)	3-10 MWe	PHASE 1 - On hold at vendor's request
4	U.S.	Advanced Reactor Concepts (ARC-100)	Sodium cooled (fast spectrum)	100 MWe	PHASE 1 - Assessment in progress
5	U.K.	Moltex Energy (SSR-W300)	Molten salt (fast spectrum)	300 MWe	PHASE 1 - Assessment in progress
6	U.S.	Holtec International (SMR-160)	Pressurized water (Integral PWR)	160 MWe	PHASE 1 - Assessment in progress
7	U.S.	NuScale Power (NuScale)	Pressurized water (Integral PWR)	50 MWe	PHASE 2*- Project start pending

Current Canadian SMR Status: Vendor Design Review
(4 service agreements are under development)

No	Country of origin	Company (Design)	Reactor Type	Elec. Output	Applied For
1	U.K.	Urenco (U-Battery)	High temperature gas cooled (graphite moderated)	4 MWe	Phase 1
2	Canada/US	StarCore Nuclear	High-temperature gas cooled (graphite moderated)	2x10 MWe	Series Phase 1 and 2
3	U.S.	Westinghouse Electric (eVinci)	Heat pipe / Nuclear battery (yttrium hydride moderated)	< 25 MWe	Phase 2
4	U.S.	GE-Hitachi Nuclear Energy	BWRX-300 boiling water reactor	300	Phase 2



Canadian Nuclear Laboratory's (CNL) Role in Advancing SMRs

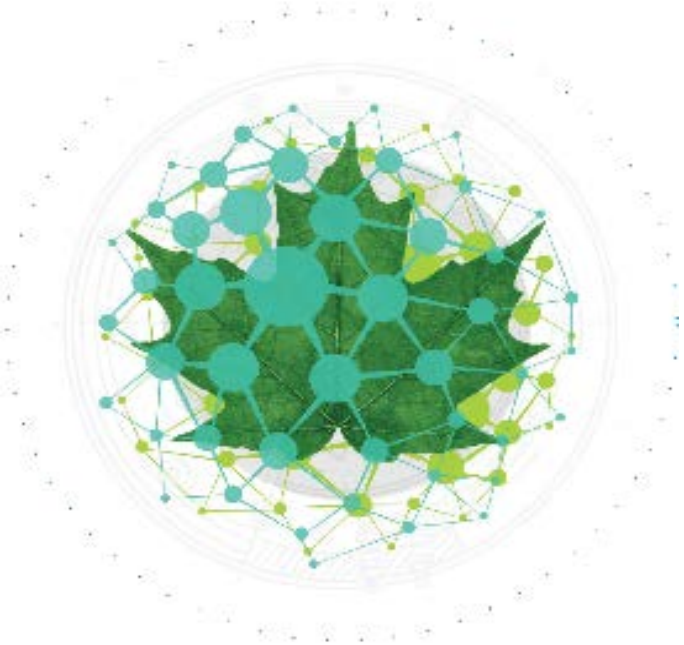
- *Nuclear R&D*
- *SMR Demonstration Project*

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CNL's Strategic Initiatives

- Small Modular Reactors
- Advanced Manufacturing of Fuel
- Decarbonizing Transport and Remote Communities (hydrogen)
- Reactor Life Extension and Asset Management
- Cyber-Security
- Nuclear Forensics
- Alpha Research Institute
- Decommissioning and Waste Management (new)





CNL's SMR Vision

"demonstrate the commercial viability of the small modular reactor by 2026."

"be recognized globally as a leader in SMR prototype testing and S&T support."

"be a recognized hub for SMRs, where multiple vendor-supported prototypes are built and tested."

"in the next 10 years … host a prototype"

Excerpts from our 10 Year Plan (www.cnl.ca/strategy)

Canadian SMR Roadmap - Nuclear R&D

Four Recommendations for AECL and CNL



Prepare Sites for SMR Demonstration Projects

Continue Invitation to site a Demonstration SMR

Consider Federal Priorities around SMRs as part of the FNST Work Plan

Advance international collaboration on SMR R&D

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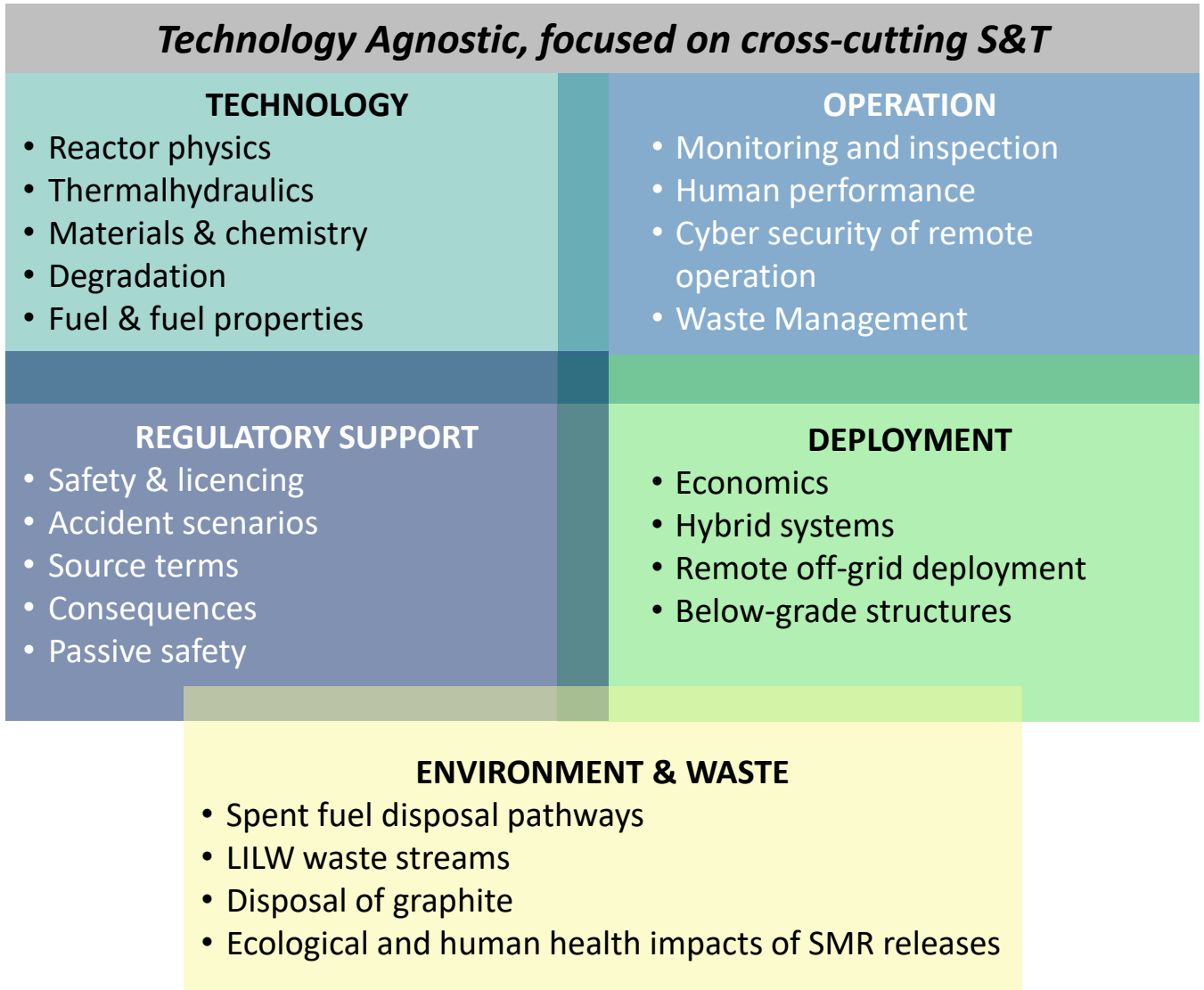
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Canadian SMR Roadmap – International Collaborations

- Canada is a member of the Generation IV International Forum (GIF) that carries out collaborative R&D needed to establish the feasibility and performance capabilities of the next generation nuclear energy systems,
- Canada is an active member in NEA's Nuclear Development Committee
- Federal government supports Nuclear Education Skills & Technology through initiatives by Canadian and international Universities
- Nuclear bi-lateral co-operations:
  - US-Canada Action Plan (2015 January)
  - Canada-UK Action Plan (2018 November)
- Nuclear Innovation Clean Energy (NICE) Future initiative by Canada, US and Japan. Open to new members and proposals https://nice-future.org



CNL's R&D program supporting Advanced Reactors and SMRs



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R&D on Molten Salt Reactors

R&D programs addresses major knowledge gaps

- Thermophysical properties of Molten Salts
  - new facilities for accurate measurements
  - molecular dynamics simulation for predicting properties
- Measurement of fission gas retention and release
- Corrosion loop for measuring corrosion of structural materials
- Coupled (physics and t/h) toolset for SMR transients
- Passive cooling during station blackout
- Development of actinide molten salt fuel synthesis
- PIRT analysis for severe accidents in MSRs

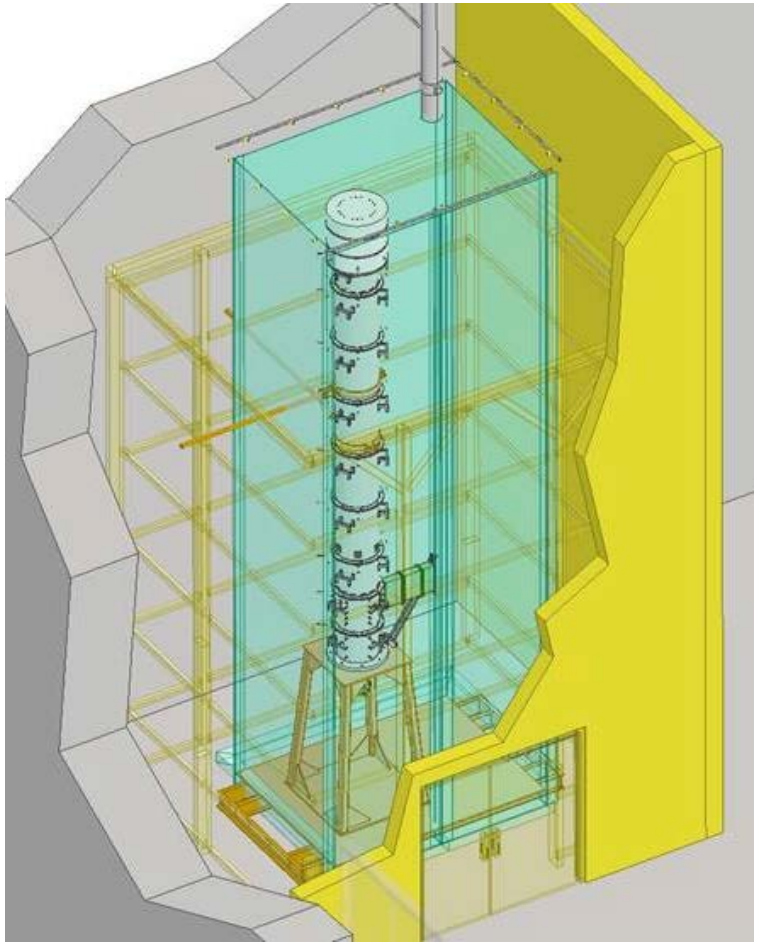


In order to support these programs experimental facilities are being developed and glove boxes are purchased. Testing has started.

R&D on High Temperature Gas-Cooled Reactors

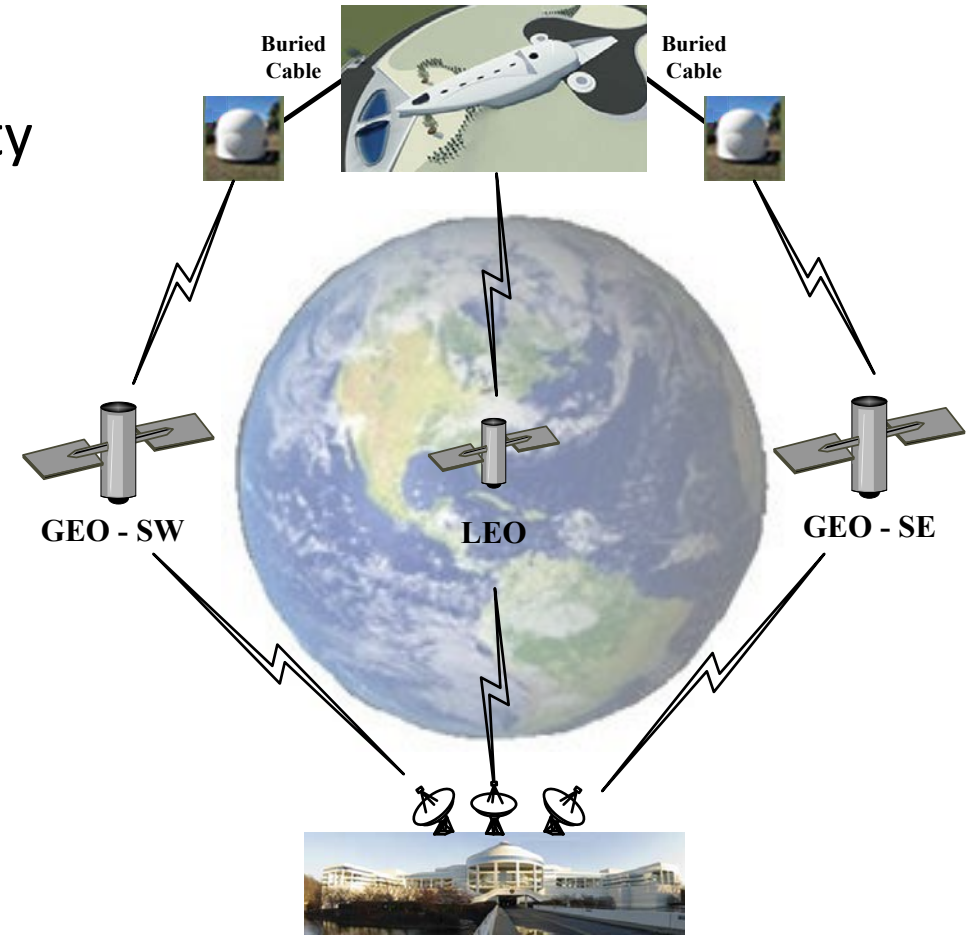
R&D programs addresses major knowledge gaps

- PIRT analysis for severe accidents
- High Temperature Air Ingress Facility development
- Reactor physics modelling
- In-house system t/h code for safety evaluations
- Passive cooling during station blackout
- EPZ size estimations/IAEA CRP
- Economics of novel SMRs including HTGR
- Irradiated graphite harvesting from NRU
- High temperature materials (from the SCWR system)



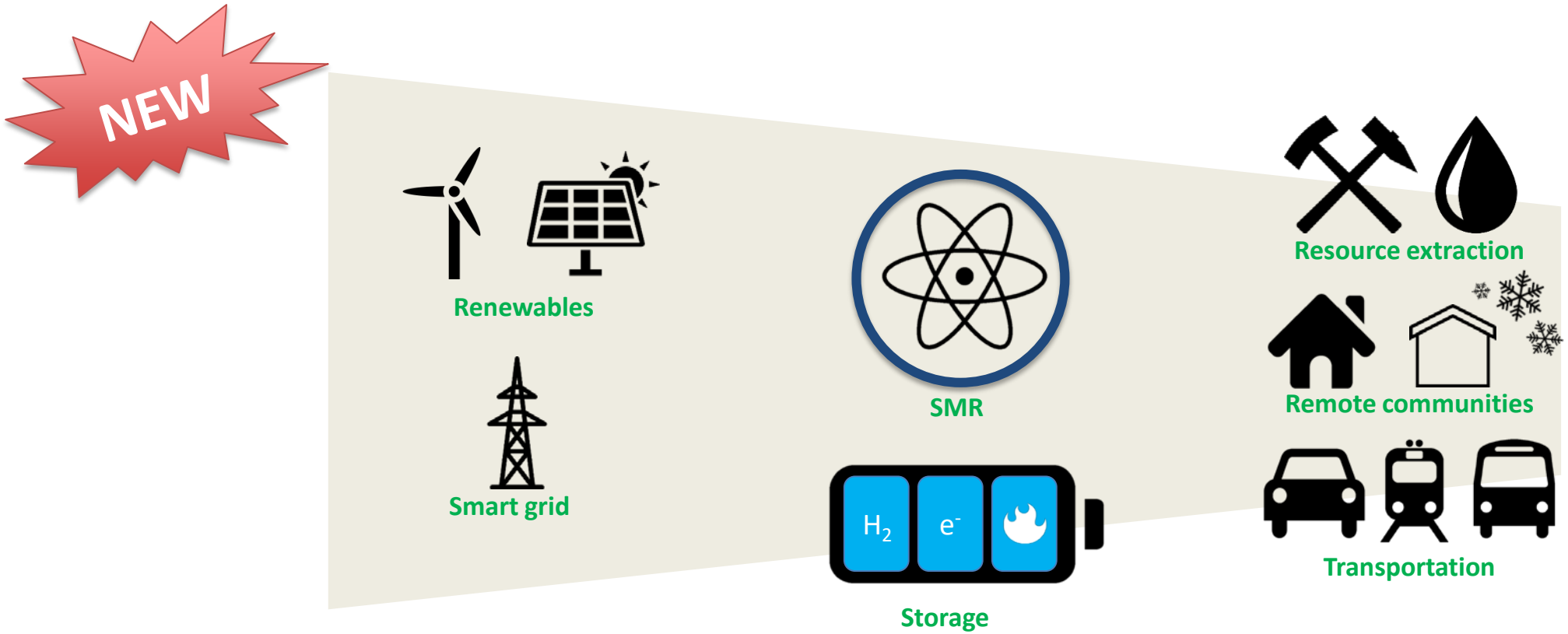
R&D on Generic Topics

- Remote Monitoring of SMRs and Cyber Security
- Monitoring structural integrity of below-grade SMR buildings
- Emergency Planning Zone Methodology and technical basis
- Hydrogen Production
- Hybrid Energy Systems
- Economics of novel SMRs
- Human Factors



Clean Energy Research Park (CERP)

- Attracting partners, supply chain and scientists



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Canadian SMR Roadmap – SMR Siting Project

Four Recommendations for AECL and CNL



Prepare Sites for SMR Demonstration Projects

Continue Invitation to site a Demonstration SMR

Consider Federal Priorities around SMRs as part of the FNST Work Plan

Advance international collaboration on SMR R&D

Market Survey (RFEOI) 2017 May

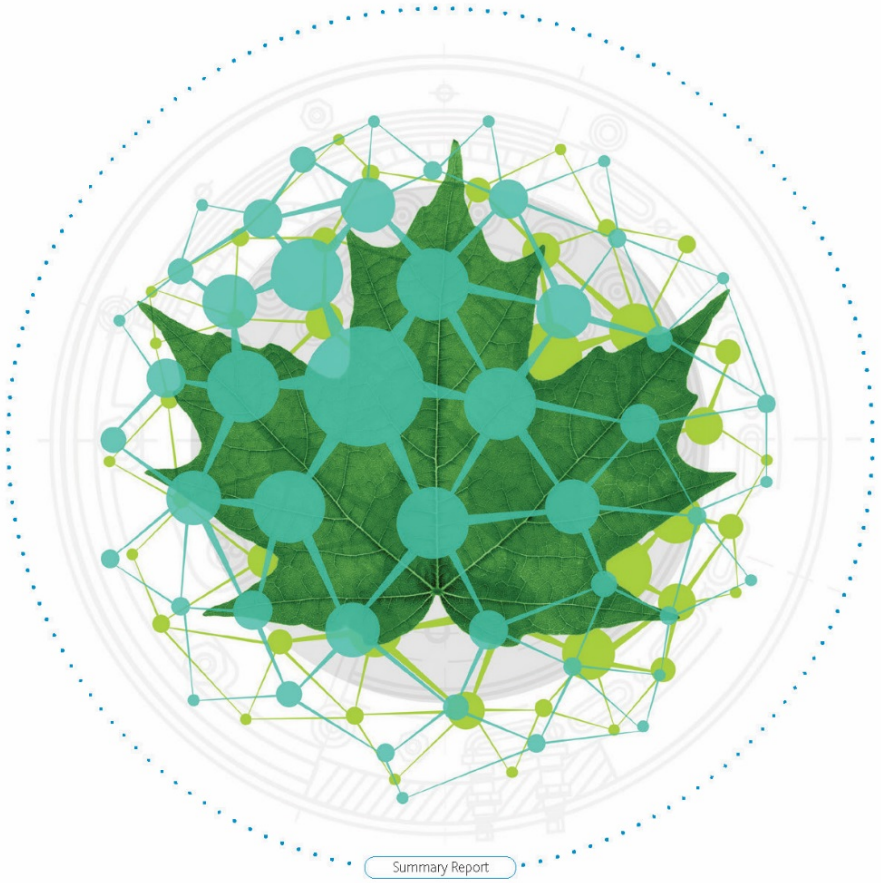
Initial Siting Invitation 2018 May

SMR Roadmap 2018 Nov

Second Siting Invitation 2018 December

Clean Energy Ministerial 2019

SMR Demonstration at Canadian Nuclear Laboratories



Request for Expressions of Interest (RFEOI) Overview

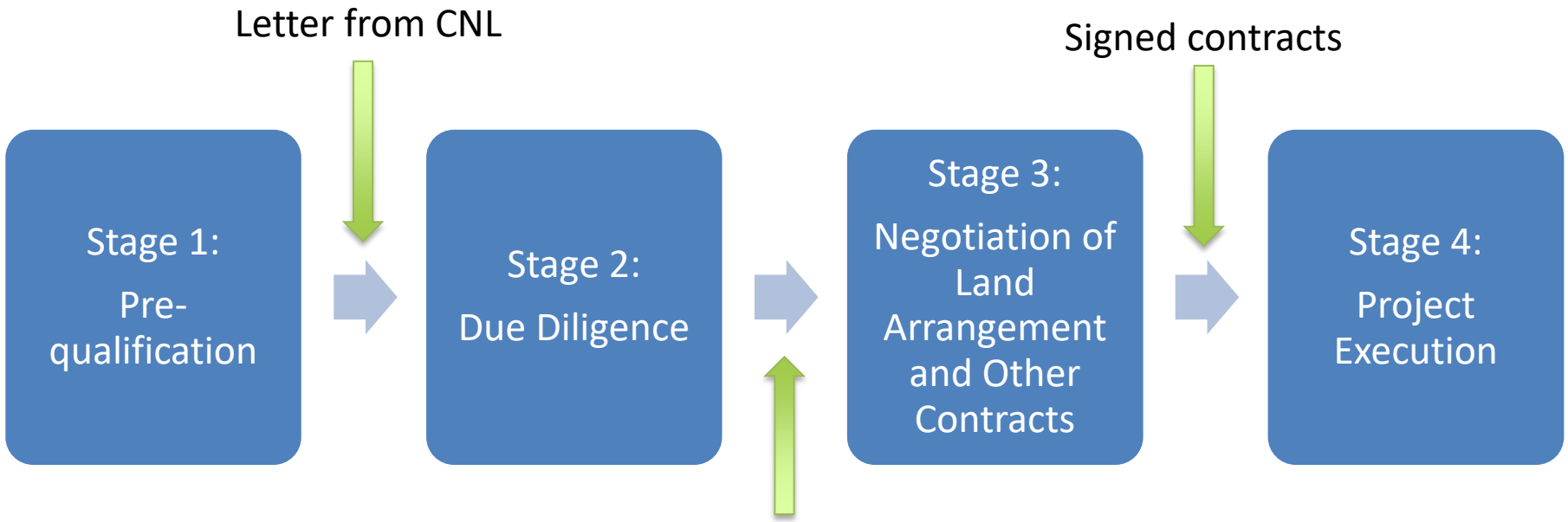
- 80 responses, 19 expressions for potential SMR demonstrations at a CNL site

Full Report Available: www.CNL.ca/SMR

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Siting Invitation for Applications – SMR Demonstrations



- Intake 1 (2018 June): Four responses
- Intake 2 (2019 January): Two responses



SMR Demonstration Siting at CRL

- Preliminary studies identified a number of potential sites:
  - 10 sites at the Chalk River Laboratories, 12 sites Whiteshell Laboratories
- Additional studies needed on specific sites and for a particular technology
  - Strategic siting (most suitable site for the SMR)
  - Environmental Assessments (must be completed)



Characterization of Potential sites at CRL

- General environmental studies planned on a subset of potential demonstrator host sites (CRL) over the next 12 months
  - Not technology specific
  - Not an "Environmental Assessment"
  - Characterization
  - Archaeological Assessments

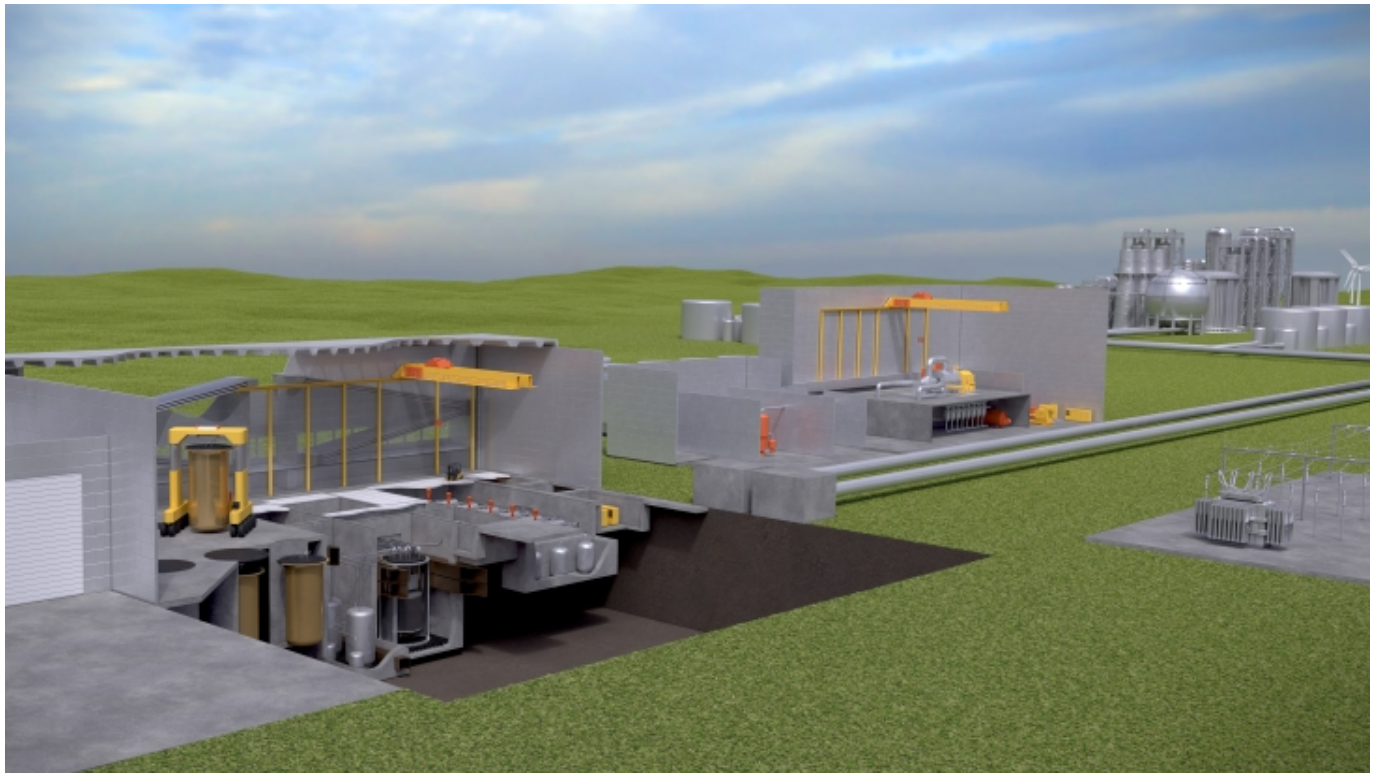
CNL Press Release - 2019 February 15

Technology developers advance in CNL's process to site a small modular reactor

- Two respondents advanced to "Stage 2" (Due-Diligence)
  - Terrestrial Energy and
  - Starcore

- One advanced to "Stage 3" (Negotiations of Land Arrangements and Other Contracts)
  - Global First Power(GFP), Ontario Power Generation (OPG) and USNC (Ultra Safe Nuclear Company)

Terrestrial Energy - IMSR



Type	Molten Salt Reactor
Fuel	<5% U-235 in molten salt
Power	190 MWe
Moderator	Graphite
Outlet Temp	700 °C
Refuelling Interval	Reactor core is replaced as a whole in every 7 years

StarCore Nuclear



Type	He Gas-Cooled Reactor
Fuel	TRISO Fuel with <20% U-235
Power	2 Units of 35 MWth (10 MWe, 15 MWth)
Moderator	Graphite
Outlet Temp	850 °C
Refuelling Interval	5 years

- Starcore is interested in siting at Whiteshell Laboraties (Manitoba, CA)
- The town of Pinawa is willing to be a host community

CNL Press Release - 2019 February 15

Technology developers advance in CNL's process to site a small modular reactor

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- One advanced to "Stage 3" (Negotiations of Land Arrangements and Other Contracts)
  - Global First Power(GFP), Ontario Power Generation (OPG) and USNC (Ultra Safe Nuclear Company)

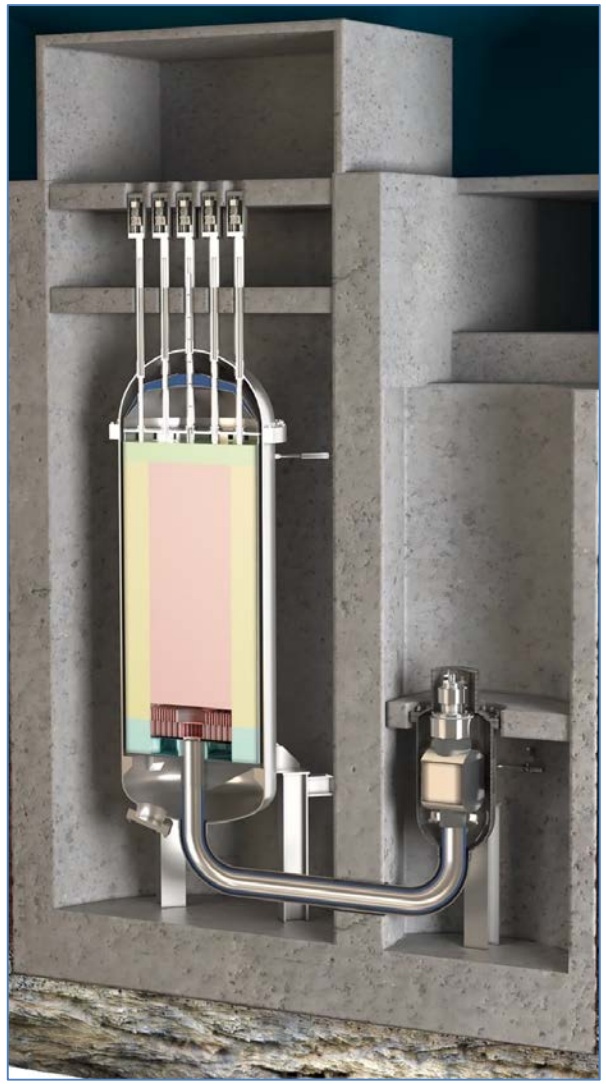
Global First Power/Ultra Safe Nuclear Corporation

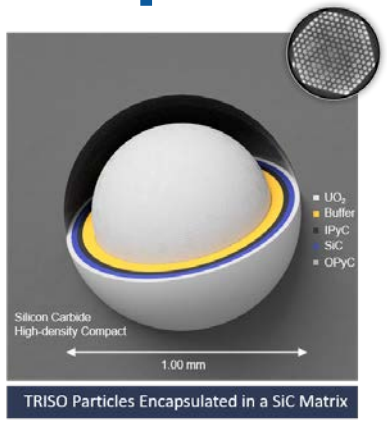
USNC (Ultra Safe Nuclear) is a private US (owned and controlled) company spinoff from the DOE Labs

- First SMR license submission in Canada

Features:

- The MMR is a 15 MW (thermal), 5 MW (electrical) high-temperature gas reactor
- Uses Accident Tolerant Fuel (TRISO in SiC matrix)
- Molten salt secondary side





TRISO Particles Encapsulated in a SiC Matrix

Type	He Gas-Cooled Reactor
Fuel	UO2, TRISO Fuel with <20% U-235
Power	15 MWth (5 MWe)
Moderator	Graphite
Outlet Temp	630 °C
Refuelling Interval	Once fuelled, 20 years

WNN world nuclear news – 2019 April 2

First Canadian SMR licence application submitted

"The Canadian Nuclear Safety Commission (CNSC) has received the first licence application for a small modular reactor. The application from Global First Power (GFP), with support from Ontario Power Generation and Ultra Safe Nuclear Corporation (USNC), supports a proposal to deploy a Micro Modular Reactor plant at Chalk River in Ontario."

This application submission is the first step ("Licence to Prepare Site") in the CNSC licensing process.

Next Major SMR Conference in Canada – Organised by Canadian Nuclear Society

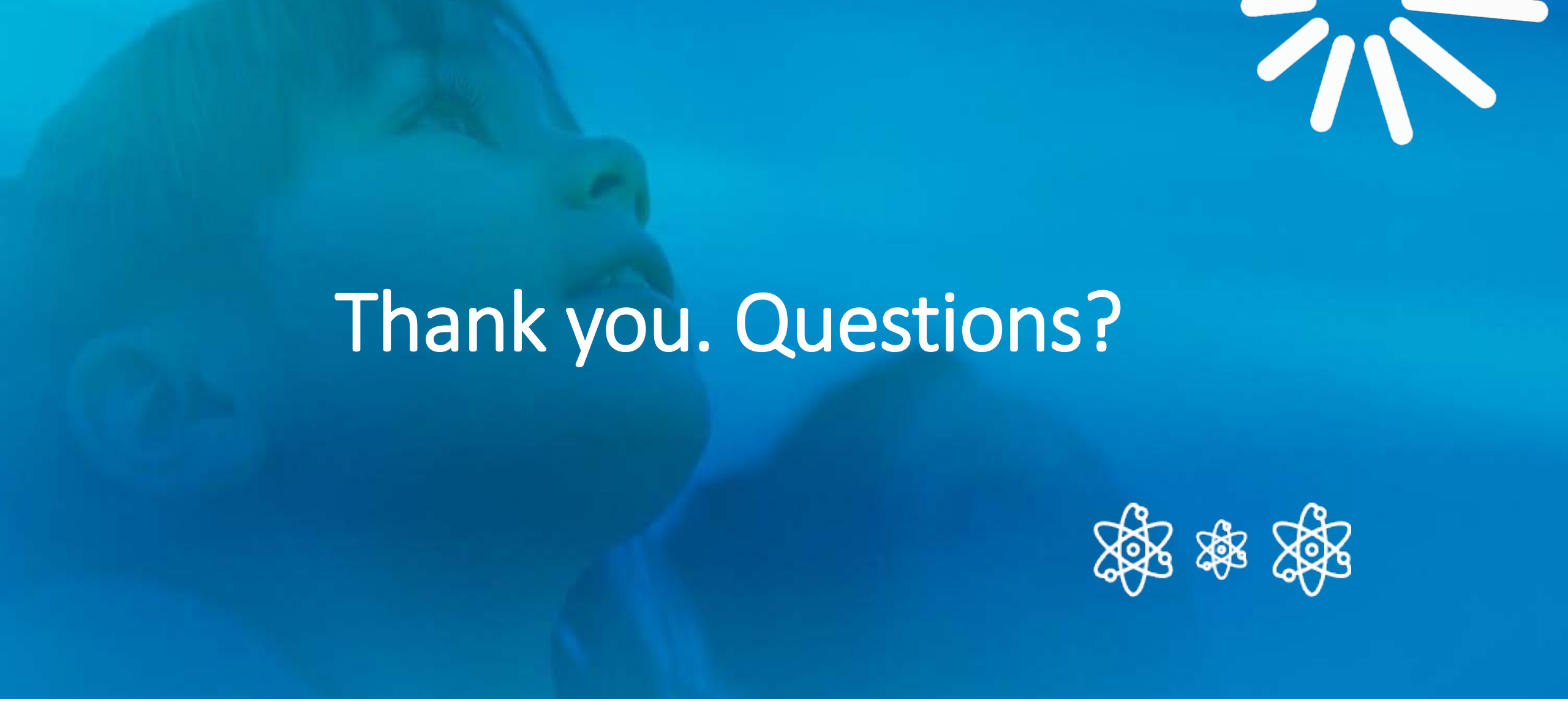
GENERATION IV & SMALL REACTORS

G4SR-2

INTERNATIONAL CONFERENCE



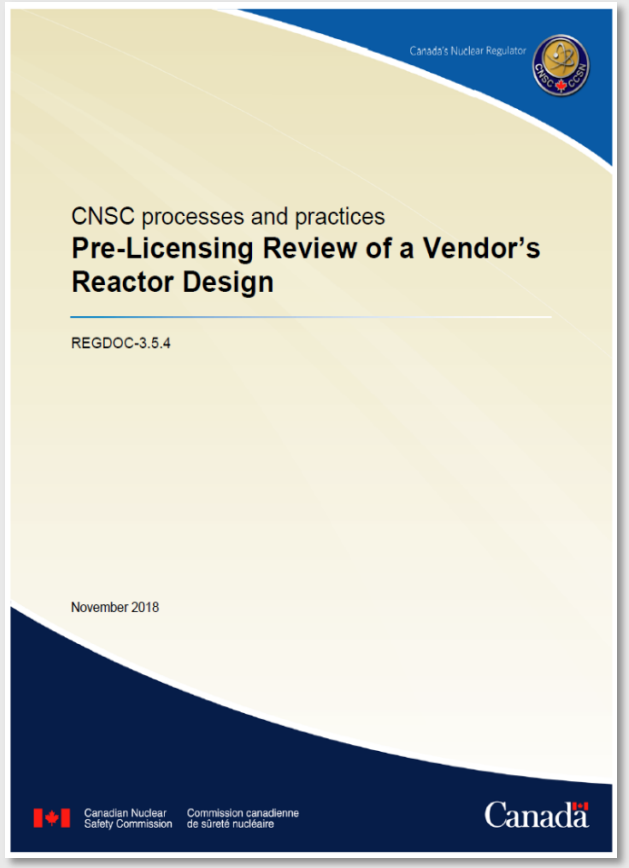
G4SR .ORG | FALL 2020 | TORONTO, ONTARIO, CANADA



Canadian Nuclear Laboratories | Laboratoires Nucléaires Canadiens

WHAT IS A VDR?

- An optional pre-licensing process that assesses:
- how the vendor is addressing Canadian requirements in their design and safety analysis activities
- key issues emerging in a design that could impact a licensing process for a potential future project referencing the vendor's design
- This process does not "approve" a generic design and is not site specific
- The conclusions of any design review **do not bind or otherwise influence decisions made by the Commission**



THREE PHASES OF A VDR

VDRs are conducted in three phases of increasing review depth and evaluates 19 cross-cutting design and safety analysis areas:

Phase 1	Phase 2	Phase 3
Evaluates that the vendor's design intent shows an understanding of Canadian requirements and regulatory language	Identification of potential fundamental barriers to licensing	Follow-up on review areas based on Phase 1 and Phase 2 outcomes

Canadian Nuclear Safety Commission - nuclearsafety.gc.ca (Peter Elder Presentation, 2019 CNS Annual Conference)